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LEVEL II

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PERFORMANCE OF COMMERCIALLY AVAILABLE FLAME ARRESTORS FOR BUTANE/AIR AND GASOLINE/ AIR MIXTURES

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FINAL REPORT

SEPTEMBER 1978

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16. Abstract

Tests were undertaken in order to provide the U. S. Coast Guard with an empirical basis for evaluating gasoline/air flame arrestors. The study was intended to be used as background information for design, inspection, and maintenance of cargo tank venting systems. Several commerically available arrestors were found to be effective in quenching butane/air flames up to 200 ft/sec flame speed and gasoline vapor/air flames up to 125 ft/sec flame speed.

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METRIC CONVERSION FACTORS

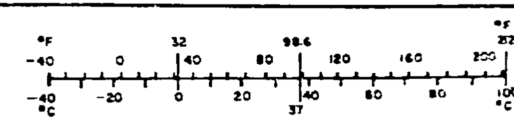
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Acknowledgement

Lieutenant Michael Flessner of the Marine Safety Branch, Division of Applied Technology, Office of Research and Development, United States Coast Guard contributed substantially in both the planning and interpretation of the experiments reported herein.

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I. BACKGROUND AND SUMMARY OF FINDINGS

A. Background

Tests were undertaken in order to provide the U.S. Coast Guard with an empirical basis for evaluating gasoline/air flame arrestors. The need to specify flame arrestors for gasoline vapor/air mixtures stems from recent EPA efforts to control hydrocarbon emissions during loading and unloading of gasoline. The Environmental Protection Agency (EPA) has issued a regulation requiring the recovery of vapor emitted during loading and unloading of gasoline from ships and barges in the Houston-Galveston Interstate Air Quality Control Region. Several U.S. Vessel loading terminals are scheduled to install Vapor Recovery Systems (VRS) to reduce the amount of hydrocarbons released to the atmosphere and to improve the ambient air quality. The U.S. Coast Guard, under the Ports and Waterways Safety Act (PL 92-340), is responsible for the safety of the VRS, as part of their responsibility for the safety of vessels and U.S. ports from the inherent hazard of handling petroleum products. The Coast Guard must insure that tank vessels are adequately protected from fires and explosions that may be generated in VRS.

A primary concern in the installation of a VRS for gasoline vapor is the inclusion of an effective flame control device to prevent the passage of any flame into the tank. Recent tests by Amoco Oil Company* have demonstrated the inability of specific flame arrestors to quench a flame which detonates through a 3" pipe filled with butane/air. The 44 ft flame run-up distance used in these tests corresponded to a pipe L/d = 176, which is much larger than would be used in a VRS system and which caused detonation in the Amoco tests. The question addressed in this report is whether, under less severe conditions which do not produce detonations (pipe L/d $\approx$ 10, 5.5 ft run-up distance), there are any off-the-shelf devices which will function properly.

*Broshchka, G.L., and Will, G.R. A Study of Flame Arrestors in Piping Systems, Project 3721, Amoco Oil Company, Naperville, Illinois, December, 1975.

The test program for VRS flame arrestors was undertaken by Arthur D. Little, Inc. as part of Contract No. DOT-CG-42357A to the U.S. Coast Guard. This ongoing study of vent systems has developed design criteria for flame control devices. The arrestor facility was modified and tests conducted to answer the question of the adequacy of commercial flame-control devices in VRS. This study is intended to be used as background information for design, inspection, and maintenance of cargo tank venting systems.

B. Summary of Findings

The following USCG-approved, commercially available arrestors were found effective in quenching butane/air flames up to 200/ft/sec flame speed and gasoline vapor/air flames up to 125 ft/sec flame speed (5.5 ft run-up length, 16 ft/sec mixture speed, upstream ignition):

- Shand and Jurs   Model 94305-16-11
- Varec   Model 50SG

In addition, three non-listed arrestors were also found to be effective:

- Amal   Model 188/905/75/24/CN (.024" crimp height)
- Amal   Model 188/905/15/45/CN (.045" crimp height)
- Retimet   No 30 Metal Foam

Finally, the Protectoseal Model 4956 was found to work for these gasoline/air flames but not consistently for butane/air.

These arrestors will be effective when used in gasoline VRS systems, provided flames are produced with approach speeds less than 125 ft/sec. For flames exceeding 125 ft/sec approach speed, the performance of these arrestors is not determined. Such flame speeds are likely if the VRS design has excessive mixture speed (greater than 20 ft/sec), run-up length greater than 10 diameters from an open exit, or some other flame-accelerating condition.

For low-speed flames (i.e., below 50 ft/sec) two additional devices were also effective. The Protectoseal Model 4956 and the Press Vac Model PL6 were effective for butane/air flames (conducted at 20-50 ft/sec) and gasoline/air flames (conducted at 3 ft/sec), had not been found to be effective at flame speeds greater than 50 ft/sec and 3 ft/sec for butane/air and gasoline/air, respectively. These devices

would be suitable for installation at pipe exits to protect against flame entry; in such installations there is no run-up length to accelerate the flame. All of the devices listed above for high-speed flames are expected to also be effective for low-speed flames. The single screen of 30 mesh x .011" diameter wire failed to quench butane/air or gasoline/air flames at velocities as low as 3 ft/sec.

The "worst case" flame condition which can be produced with the ADL facility (as currently arranged) was determined to be as follows:

- 16 ft/sec mixture speed;
- Ignition upstream of the arrestor;
- 5.5 ft run-up distance; and
- Gas expansion constricted by mixing tee and blow out pipe.

This condition, for both butane and methane, produced rapid flame acceleration with flame speeds up to 200 ft/sec approaching the arrestor, and gave rise to pressures up to 40 psi. For methane/air, the flame speed is apparently not a strong function of mixture speed, and achieves a level of 140 $\pm$ 15 ft/sec for downstream ignition and about 200 ft/sec for upstream ignition. For butane/air, upstream ignition produces flame speeds from 160 to 280 ft/sec (highest for 16 ft/sec mixture speed), whereas downstream ignition produces flame speeds from 30 $\pm$ 20 to 125 $\pm$ 50 ft/sec (highest for 2 ft/sec mixture speed).

In line with the findings of Broshchka and Will (1975), it was found that flame propagation from outside a pipe can be prevented, if vent speeds are maintained in excess of 10 ft/sec, for both butane and methane. This holds provided the ignition source is no more than 2 ft inside the end of an open-ended 6" pipe.

Tests on parallel plate and crimped ribbon arrestors, varying both gap and length, show that the design criteria for flame arrestors are that (a) effective length L must exceed 1.00" and (b) the hydraulic diameter of the gap must be less than .016". These criteria are applicable to hydrocarbons other than acetylene for flames up to 200 ft/sec approach speed.

C. Vapor Recovery Systems and Applicability of Results

Before presenting the experimental methods and test results, it is appropriate to review the conditions for flame propagation in Vapor Recovery Systems, in order to establish how these conditions were simulated using the ADL test facility.

A schematic diagram of a vapor recovery system for a loading terminal is shown in Figure 1. As gasoline is loaded into the cargo tank, vapor is generated and mixes with air in the ullage space.* The venting system is designed to discharge the displaced gas mixture to prevent pressurization of the cargo tank. A flame control device is normally fitted on the vent system near the outlet in order to prevent flame propagation from the deck area into the confined tank; the major focus of the subject contract to date has been the design of this flame control system.

The installation of a vapor recovery system raises the potential for two additional flame propagation scenarios:

(a) the deck fire may spread into the coupling of the vent system to the vapor return line (particularly if a vacuum-assist design is selected),

(b) any ignition source on shore near the condensing system may be spread into the vapor return line.

These ignition sites are marked with stars (*) on the figure. The flame conditions cited in Figure 1 were simulated in the existing facility, with three limitations:

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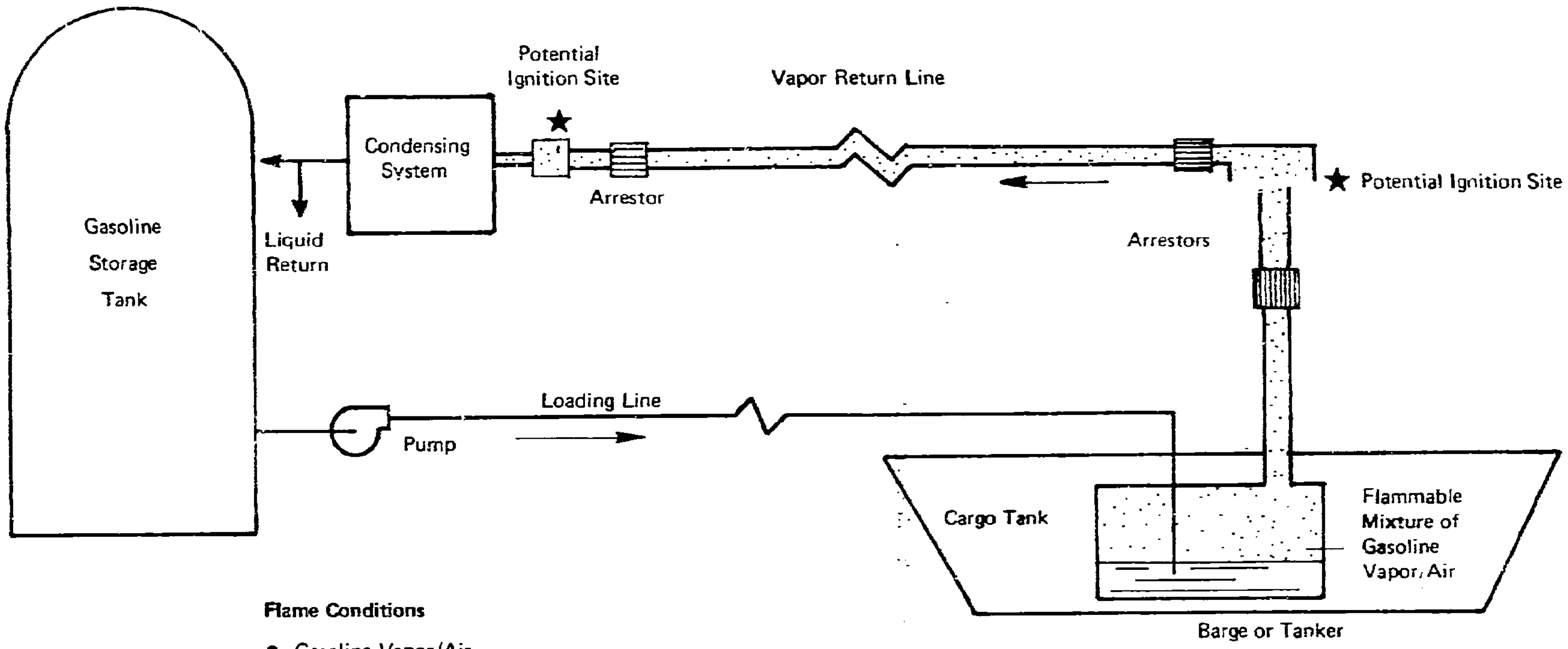
*On truck loading systems, the mixture is often rendered non-combustible by propane "spiking". Inerting with combustion products (CO_2, N_2) is also practiced. These techniques are relatively expensive options for tankers and barges.



Flame Conditions

- Gasoline Vapor/Air
- Near Stoichiometric Air/ Fuel Ratio
- 30 – 120° F
- 10 – 20 Ft/Sec
- 6" – 18" Pipe Diameter
- 50 – 200 Ft. Length (Minimum Run-Up Due to Arrestor Placement, However)

FIGURE 1: **SCHEMATIC OF FLAME HAZARDS IN VAPOR RECOVERY SYSTEMS (LOADING TERMINAL)**

(a) Diameter: The present facility at 6" diameter is at the lower extreme of piping systems used on terminal VRS.

(b) Mixture speeds: The present facility at 20 ft/sec is comparable to the normal VRS mixture speeds, but may be below that of some special high-speed designs.

(c) Run-up length: The existing facility has a 5.5 ft run-up length which produces flame speeds up to 300 ft/sec at the arrestor. The test data reported herein are applicable only for arrestors placed within 5.5 ft of an ignition source. In particular, the findings are not applicable to VRS designs which could produce detonations.

II. EXPERIMENTAL METHODS

A. Test Facility Description

1. General

The flame arrestor apparatus consists of a 6"-diameter cylindrical test section, controls and instrumentation. A controlled flow of a specified flammable gas mixture is allowed to pass through the test section (containing the flame arrestor) and is ignited at the start of the test by a spark discharge. The resulting combustion wave accelerates toward the arrestor. The performance of the arrestor is automatically recorded. A photograph and schematic of the apparatus are given in Figures 2 and 3, respectively.

2. Test Section

Referring to Figure 3, the test section consist of 6-inch diameter vertical pipe (schedule 40), 17-feet high, with a flame arrestor housing located midway up the pipe. Provisions for both mixture preparation and pressure relief are at the base of the pipe which is connected to a 6-inch "Tee". A 6-inch diameter by 6-feet long pipe extends horizontally from the Tee and is capped with an air-tight 3-mil polyethylene blow-out membrane. Its purpose is to relieve the pressure rise during combustion. The remaining leg of the Tee is connected to an air supply blower (Hauck* Model TBA16-3-0-3, 465 SCFM, 16 oz. capacity) by way of a 4-inch diameter by 4-feet long pipe which incorporates a Meriam Model 50MY15-4 Laminar Flow Element (LFE) flowmeter, a Hauck 4"-diameter butterfly throttling valve, and a thermocouple for sensing air temperature.

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*Mention of specific manufacturers and models is made solely for clarification and should not be interpreted as a recommendation or endorsement by Arthur D. Little, Inc.

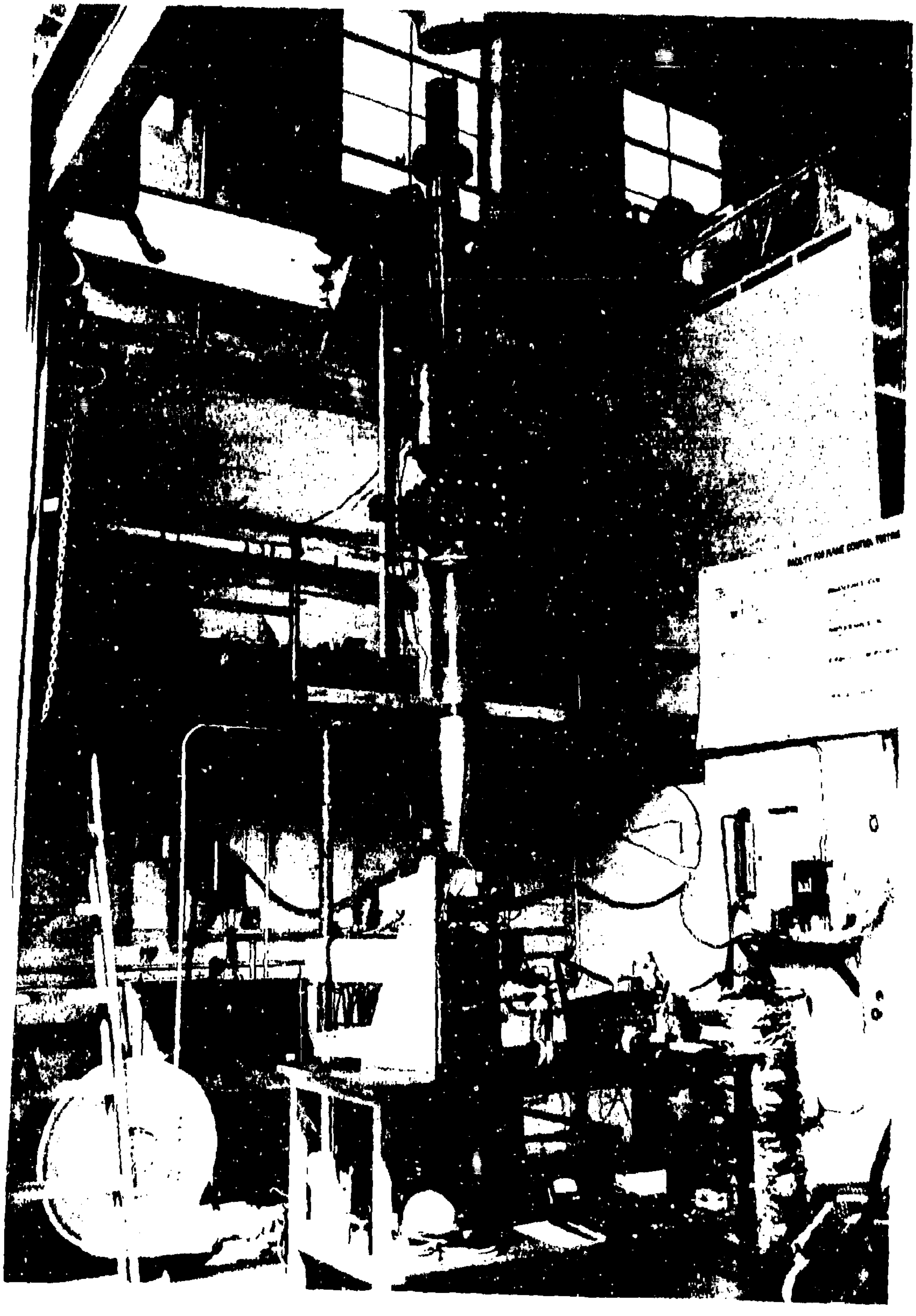

Figure 2: Facility for flame control testing

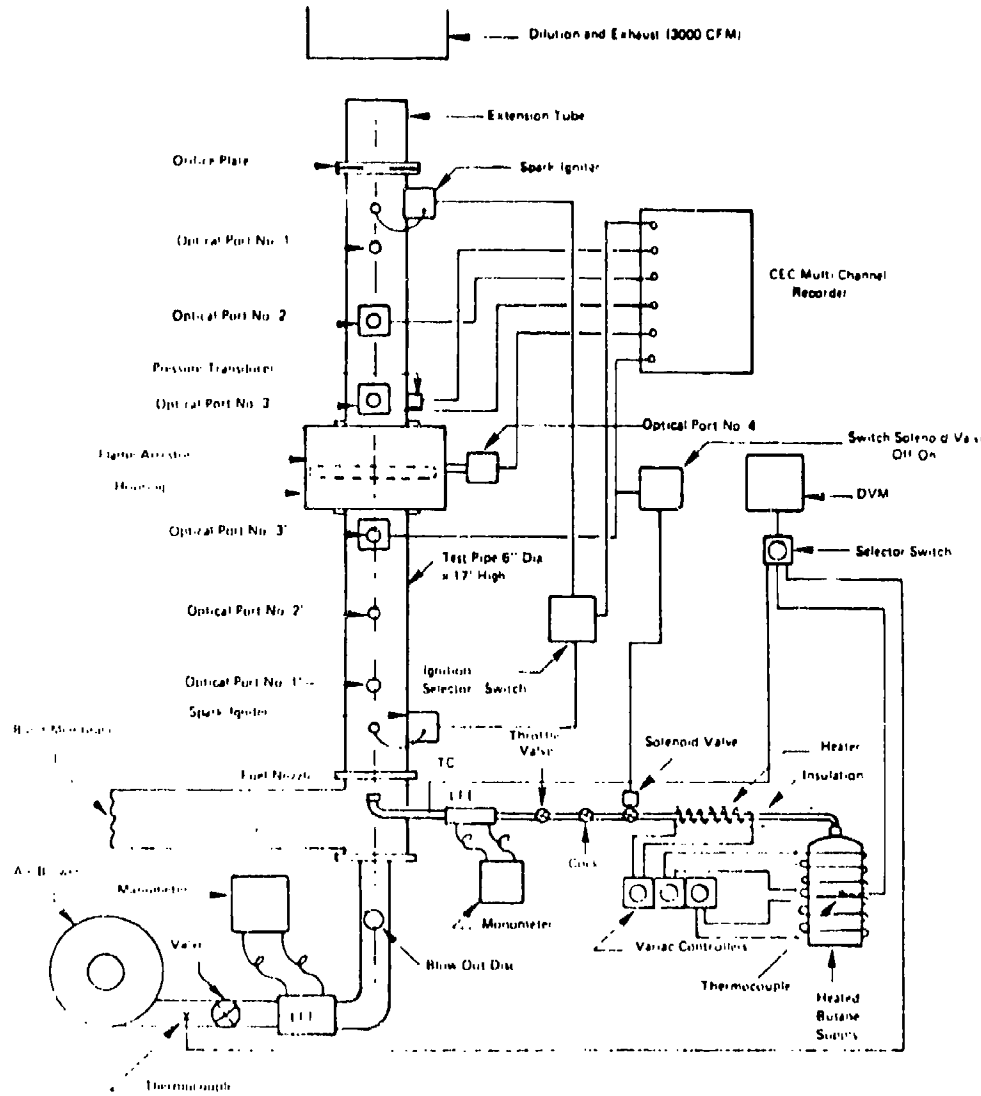

FIGURE 3 FLAME ARRESTOR TEST APPARATUS

The actual flame arrestor device is located midway up the vertical pipe section, 7.75 feet up from the top of the Tee. Commercially available arrestor housings were attached to the test pipe using standard 6-inch flanges. To permit testing of special arrestor designs fabricated at ADL, a special universal mount was fabricated using a Varec 50SG arrestor housing. (See Figure 4.)

The flame run-up distance could be controlled by adjusting the ignitor location using pipe sections of various lengths above the flame arrestor. In standard configuration, the ignitor was placed 56" above the arrestor housing flange near the top of a 64" section of pipe. This arrangement put the ignitor 66-68" from the arrestor, depending on arrestor thickness. An orifice plate was attached 8-inches above the ignitor in order to control the expansion of burned gas and thereby control flame acceleration. For example, a 3"-diameter orifice was used to generate high-speed flames (50-500 ft/sec), whereas an open pipe was used for low-speed flames (below 50 ft/sec). An 18" long pipe extension was installed above the orifice plate. An 18-inch diameter exhaust duct (3000-CFM capacity) was located 12-inches above the end of the pipe extension.

Fuel gas was supplied to the test section through a perforated one-inch diameter capped tube located in the center of the Tee. The nozzle shown in Figure 5 was designed to achieve rapid mixing with the air. Tests of concentration decay showed that complete mixing was achieved 89" above the nozzle, at the downstream spark location. Radial concentration variations at the upstream spark location (36" above the nozzle) were observed to be $\pm$ 8% or less, depending on mixture speed. Plumbing from the nozzle extended through the wall of the Tee and was connected to the fuel supply tank. The one-inch copper line

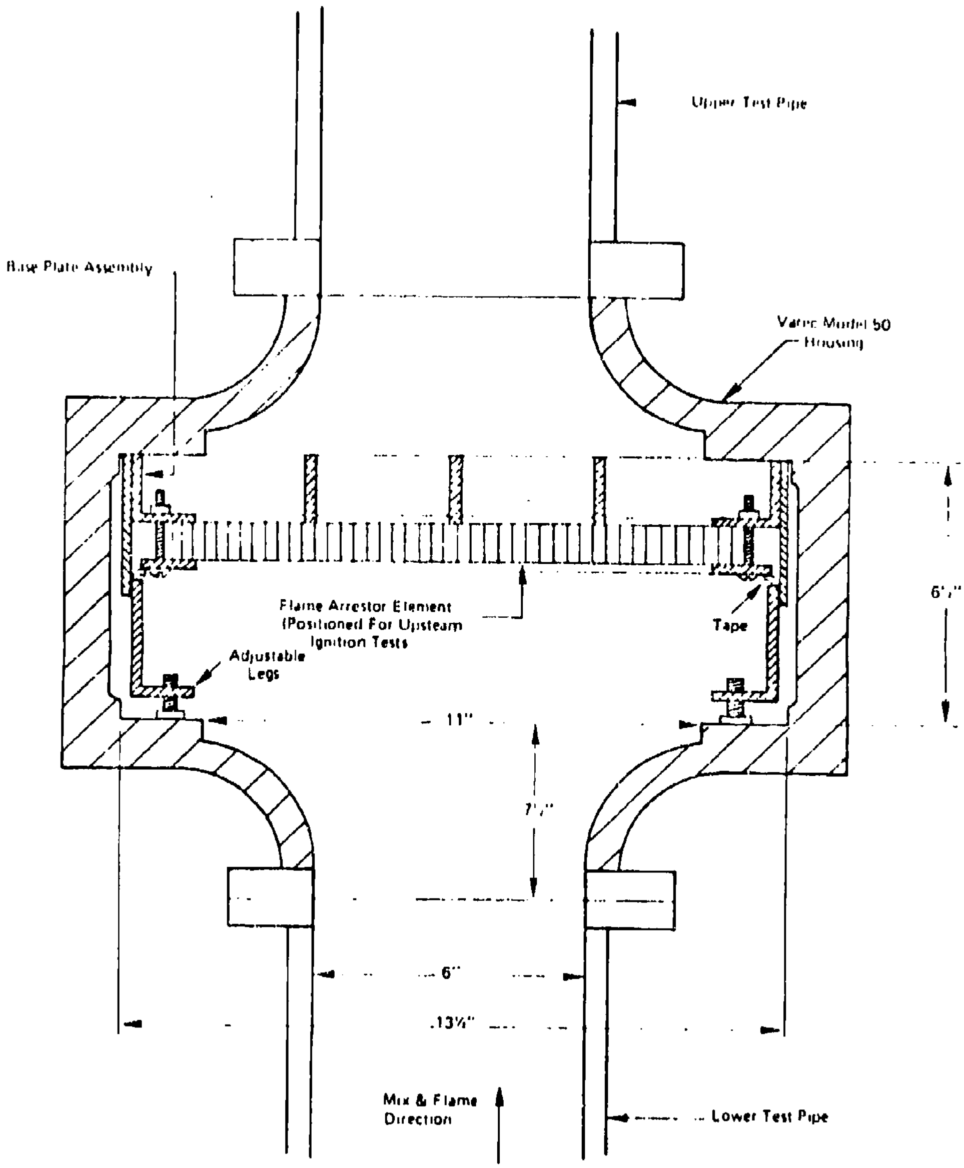

FIGURE 4 HOUSING FOR EXPERIMENTAL FLAME ARRESTORS

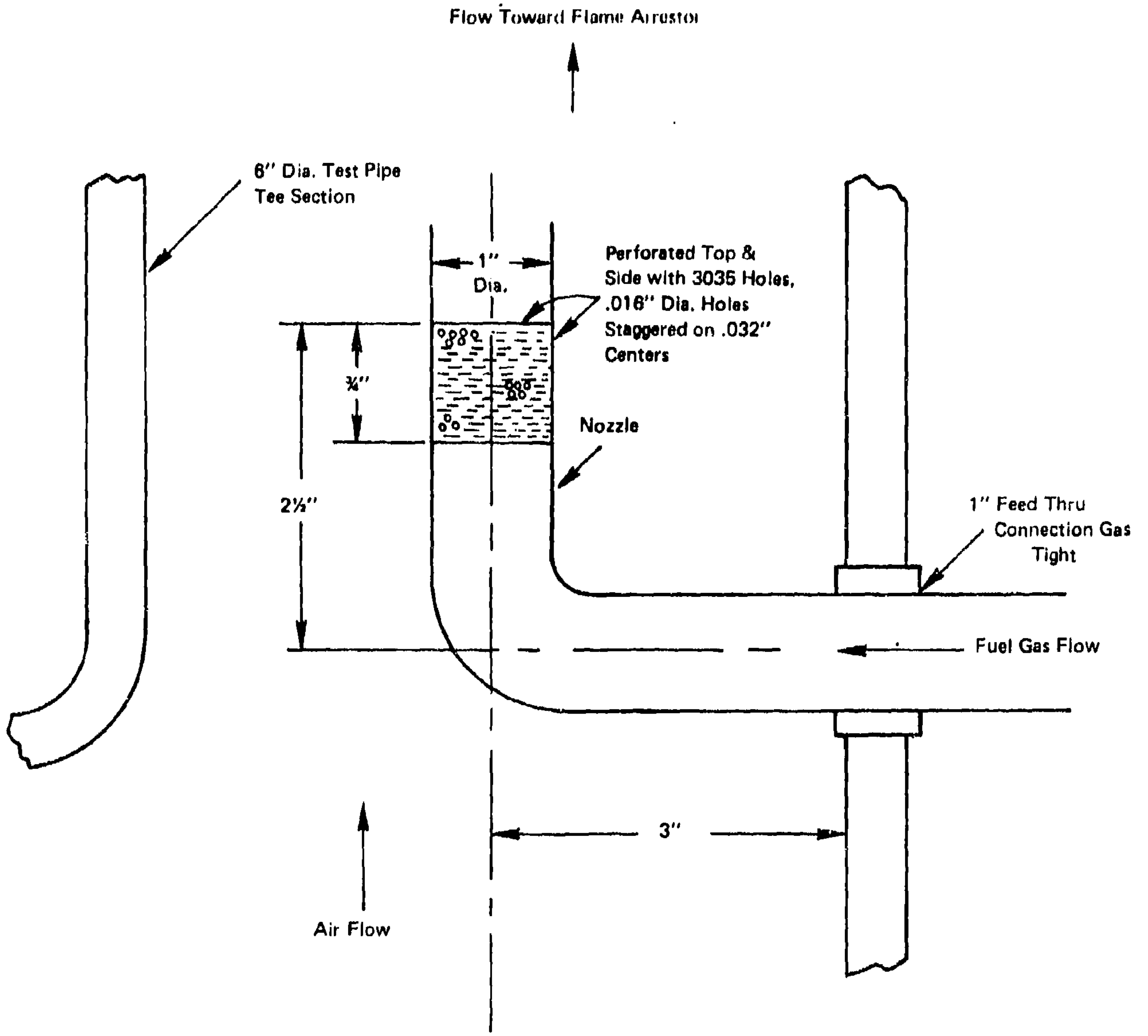

FIGURE 5 FUEL NOZZLE ARRANGEMENT

between the fuel nozzle and fuel supply tank incorporated a Meriam Model 50W20 1F LFE flowmeter, a Jenkins manual throttling valve, a manual shut-off cock, an ASCO 8210B54 solenoid operated valve, and an inline heater element.

Butane, methane, and gasoline vapor were used during the program discussed below. One-inch copper piping was selected to minimize resistance to butane gas flow. The butane supply tanks were wrapped with 2 Briskeat heating tapes (Type BIH-61) for controlled heating to approximately 100°F in order to raise the supply gas pressure to a level sufficient to ensure the flow rates required for the tests, i.e., up to 7 CFM. The inline heater was used to further raise the gas temperature to approximately 120°F to avoid condensation of the butane gas as it expanded through the throttling valve.

Gasoline vapor was generated in a converter described below. The gasoline vapor flow rate was controlled through a combination of N_2 carrier gas flow rate, N_2 temperature (controlled to 120°F), liquid gasoline temperature (controlled to 110°F), and liquid gasoline circulation rate (controlled to 275 ml/min). In line heaters, operating at a total of 1500 watts, were used to maintain the vapor/N_2 mixture at approximately 110°F to avoid condensing the vapors before blending with air.

3. Controls and Instrumentation

A summary of the instrumentation is given in Table 1.

Air flow rate was controlled by way of the Hauck butterfly throttling valve. An LFE flowmeter served to determine the flow rate; a Meriam Model A-844 manometer used to measure the pressure drop. Air temperature was measured using a Grounded sheath type thermocouple (Omega Type CAIN-116G024) located at the center of the blower exit. The thermocouple was connected via a selector switch to a digital voltmeter (DVM, Dana Model 4470). A crushed ice bath was used to give a reference temperature for all thermocouples.

Fuel flow rate was controlled by way of the throttling valve. An Ellison Model-IN manometer was used to measure the pressure drop across the LFE flowmeter from which the flow rate was determined. Fuel gas temperature was measured using an Omega CAIN-116G-24 thermocouple installed in the fuel line between the LFE meter and fuel nozzle. The thermocouple was connected to the DVM via the selector switch.

The butane supply tank heaters and the inline gas heater (595 watt, Briskeat-BIH-61 tapes wrapped over an electrically insulated layer) were controlled using Variac autotransformers.

Ignition of the flammable gas mixtures was accomplished using either of two spark ignitor systems, one located 56" above the upper flange of the arrestor housing (8" down from the orifice plate flange), the other located in the lower test pipe section (56" down from the lower arrestor housing flange). Each spark ignitor was an Auburn Model 1-33 with a 23" long center electrode. A side wire was welded to each ignitor so that the actual spark was located at the center

Table 1

Summary of Instrumentation

Variables Measured	Measuring Instrument	Accuracy
Air flow rate	Meriam 50 MY 15-4 Flowmeter with Meriam A844 Manometer	± 0.5%
Air temperature	Omega CAIN-116G-24 Thermocouple	± 1°F
Gas flow rate	Meriam 50W201F flowmeter with Ellison IN Manometer	± 0.5%
Gas temperature	Omega CAIN-116G-24 Thermocouple with Dana 4470 Digital Voltmeter	± 1°F
Flame speed	ADL fabricated photodetector system with EG&G HUV 1000 B sensors - 3 units	± 5% of the value
Flame-through event	ADL fabricated photodetector system with EG&G HUV 1000 B sensor - 1 unit	Positive detection
Test chamber pressure	Kulite XTS-190-200 pressure transducer & ADL fabricated operational circuitry	± 0.5 psi
Spark ignition event Gas Solenoid valve shut off event Photodetector event signals Pressure transducer signals	CEC 5-125 Oscillograph Recorder, 8 channel	Unspecified
Barometric pressure	National weather service - local area	Unspecified
Arrestor Temperatures	Chromel/Alumel thermocouples	± 10°F

line of the test pipe. The spark gap at the center point was approximately .06". Power to each ignitor was provided by a high-voltage ignition transformer (Jefferson Electric Model 638-171, 110 vac-250 ma primary, 10,000 V-23 ma secondary). Both transformers were connected via a selector switch to an ignition switch. Thus, either ignition system could be readily used.

Four optical detector systems assembled by ADL were used to detect flame passage through the test pipe. The electronic circuitry for the detectors was that specified by the manufacture of the detector (EG&G Model HUV-1000B with amplifier). The detectors were housed in a light-tight aluminum box 3" x 4" x 5" with a 7/8" dia x 3-inch long extension tube (see Figure 6). The extension tube, whose purpose is to remove the photo-detector circuit from the heat of the test pipe, was slip fitted over an Auburn Type P-50 observation window, machined to accommodate it, that was threaded into the test pipe (1/2" NPT) in a direction normal to the pipe axis. A horizontal viewing slit in the window restricted the angle of view of the detector element in order to achieve more precise measurements of the passing flame front.

The system was arranged so that the optical detector locations could be readily interchanged depending on whether ignition took place in the upper or lower test pipe sections. Figure 3 shows the location of the various ports for the detectors. When ignition occurred in the upper test pipe, ports 2, 3, and 4 were used for detecting flame passage while port 3 was used for detection of flame-through at the arrestor. The optical detector in port 3'was also connected via a power amplifier to the fuel solenoid valve. In the event of flame-through, the fuel solenoid would automatically shut off. For ignition in the lower pipe section, ports 1', 2', and 3'were used for flame-passage detection and port 3 was used for flame-through and automatic shut-off.

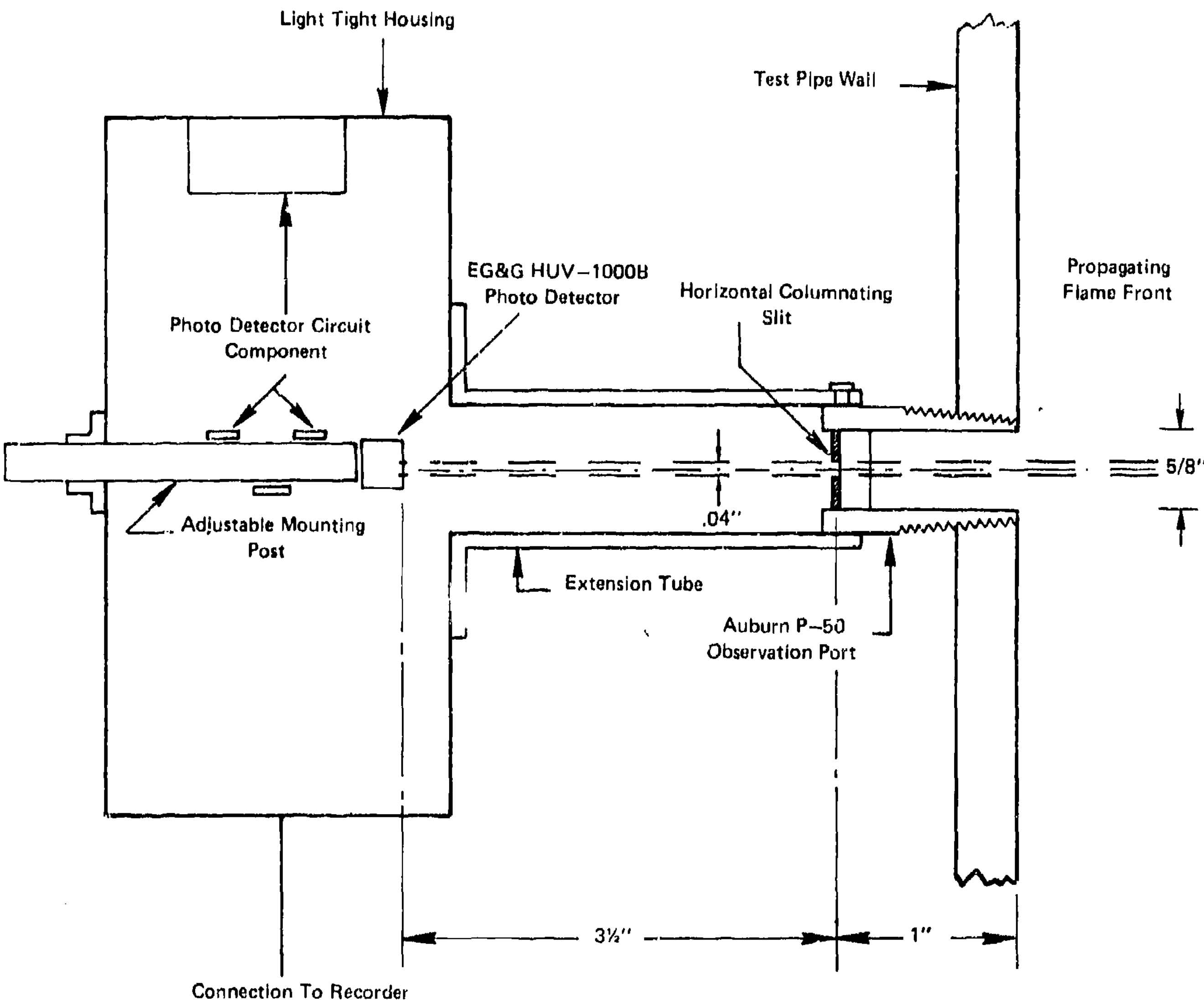

FIGURE 6 PHOTODETECTOR ARRANGEMENT

The test assembly was also provided with means of measuring the instantaneous pressure levels generated in the test pipe by the combustion of the gases. For this, a Kulite Model XTS-190-200 pressure transducer and appropriate circuitry (recommended by the manufacturer) was used. Like the optical detectors, the location of the pressure transducer could be readily changed according to the test circumstance. The transducer was mounted in 1/4-inch NPT elbow fitting and the elbow fitting was threaded into the test pipe (see Figure 7). In this way the transducer was located out of the path of direct radiation from the flames. (In early tests direct radiation appeared to have an effect on the transducer signals.) The transducer was located 44" from the arrestor, at the same station as optical port No.2.*

An eight channel recorder (CEC Model 5-124) was used to record signals from the instrumentation. The three optical detectors and the pressure detectors were connected directly to the recorder. The signal from the flame-through detector was, as mentioned above, connected to a power amplifier to shut off the fuel solenoid. This signal was also connected to the recorder so that the flame-through event could be recorded. A signal from the ignition switch was also connected to the recorder to record the existence and duration of the spark discharge.

4. Gasoline Vapor Converter

A system was set up to produce steady state vaporization of gasoline liquid for supplying gasoline vapor to the flame arrestor test apparatus. The system, shown schematically in Figure 8, consisted of a heated packed column containing approximately 1.6 liters of liquid gasoline, a 10-gallon reservoir, a circulation system, and a heated nitrogen gas supply. The system was designed to saturate a 3.5 CFM flow of nitrogen with gasoline vapor, producing a vapor mole fraction of about 0.4 depending on nitrogen temperature.

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*In Figure 3 the pressure transducer is shown opposite optical port No. 3; this was not the standard position.

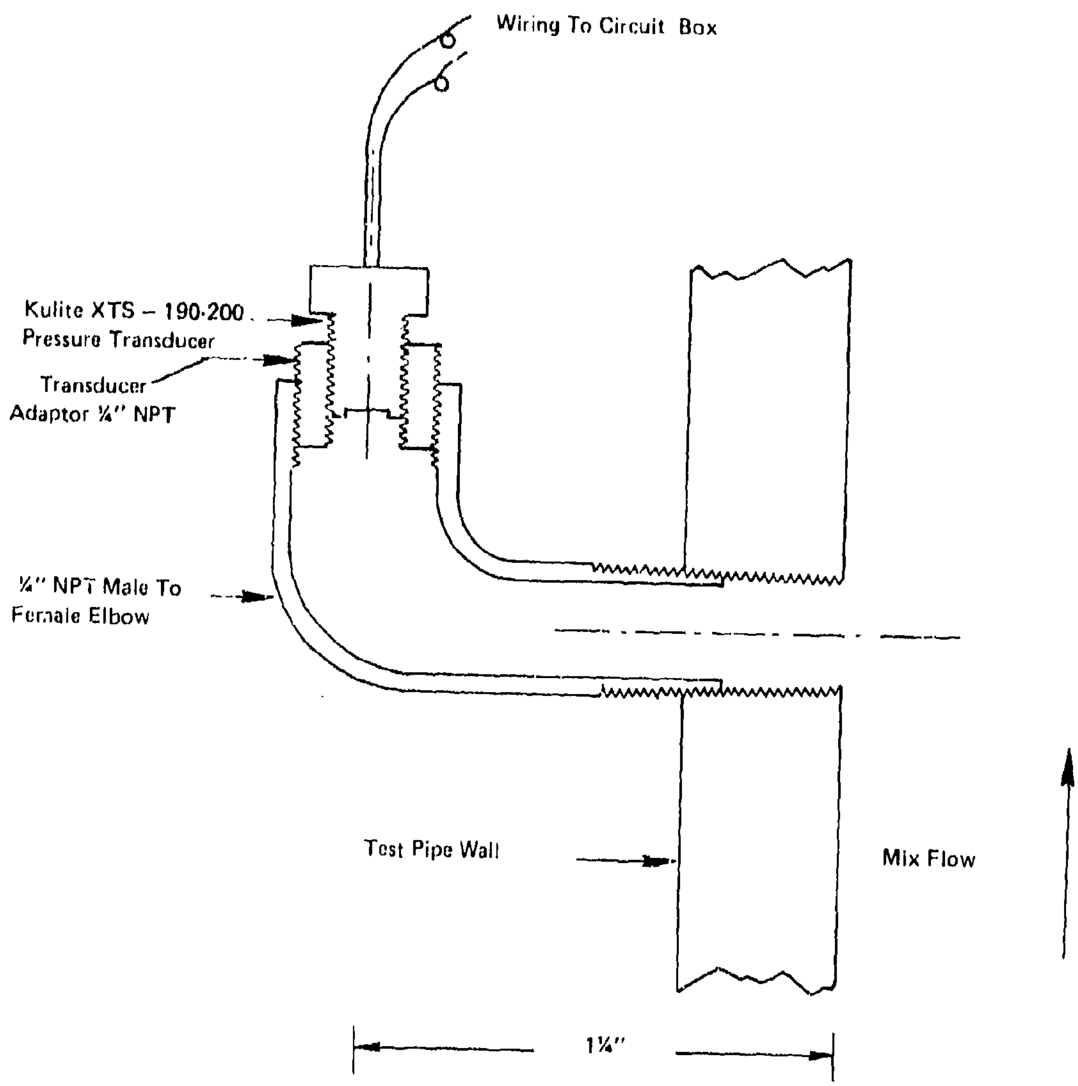

FIGURE 7 DETAIL OF PRESSURE TRANSDUCER MOUNTING

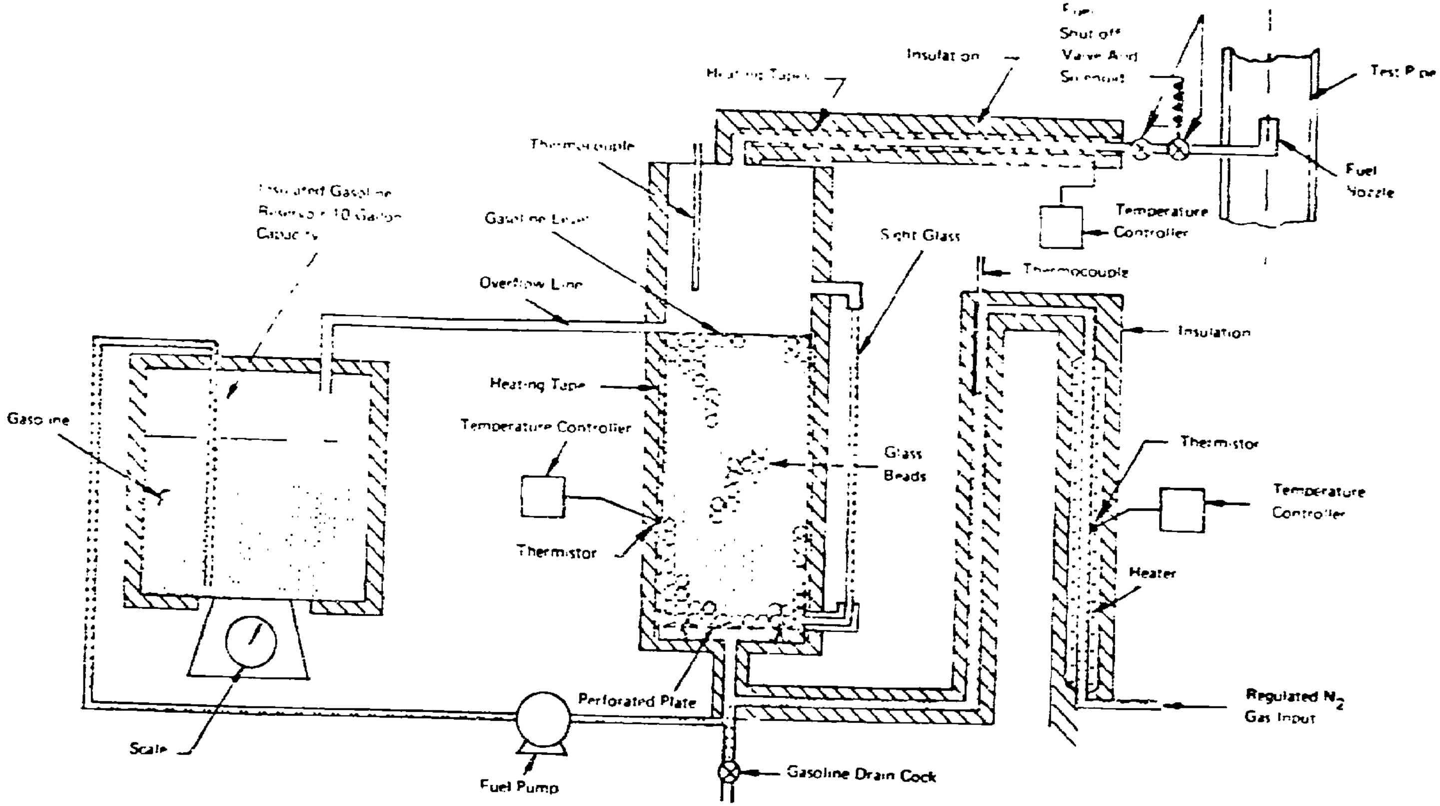

FIGURE 6 GASOLINE VAPOR CONVERTER

The packed column consists of a 3-3/4" I.D. x 30" long closed stainless steel tube having a 20" long sight tube approximately centered along side of the tube. The tube is filled to approximately 20" with glass beads packed on top of a perforated plate that is positioned 1/2" up from the bottom of the tube. A regulated flow of nitrogen gas (measured using a Fisher Model FS 1/2-27 G-10/80 flowrator) is passed vertically upward through a heated 1/2" copper tube 28 inches long. The tube contains an integrally wrapped 500 watt heater that is automatically temperature controlled using a solid state temperature controller (RFL Model 72-115) and a thermistor mounted directly on the heater. A thermometer located approximately 12 inches downstream of the heated portion of the tubing is used to monitor N_2 gas temperature. The N_2 gas then passes vertically down a 31-inch long section of 1/2" pipe to a point where it enters the bottom of the vapor converter. A gasoline drain cock is also located at the bottom of the converter.

A 10-gallon reservoir is connected to the packed column via a variable speed pump supply line and an overflow return line. This arrangement provides for a continuous circulation of heated gasoline (circulation rate 270 ml/minute). The reservoir is located on a sensitive scale (precision $\pm$ 2 gm) to permit a continuous monitor of the reservoir gasoline weight throughout the testing period.

A 575 watt Briskeat heating tape (Model BIH-16) is also wrapped around the converter tube body. Its temperature is automatically controlled using a temperature controller (RFL Model 72-115) and a thermistor mounted directly on the tube body. The converter body and all the associated plumbing are insulated with fiberglass insulation and aluminum foil. The temperature of the converter body and the interior of the ullage space above the liquid are measured using thermocouples whose output is read on the Dana DVM. The fuel line from the converter to the fuel valves is electrically heated using

three (Briskeat) heating tapes to prevent recondensation of the gasoline.

Figure 9 illustrates the vaporization characteristics of the system. After each period of operation, the average vaporization rate was determined by weighing the system after refilling the column to a fixed level. In determining vaporization rate, the pump was allowed to circulate gasoline through the heated packed column for a period of approximately 30 minutes. During this time no nitrogen gas was allowed to bubble through the column. When the packed column temperature had reached steady state (circulation rate was constant), the reservoir weight was determined with the packed column full. Then heated nitrogen gas was bubbled through the column at a rate of 3.5 CFM for a period of one-minute. At the end of one-minute the nitrogen gas was shut off and the pump allowed to continue circulating the gasoline for a period of approximately five minutes. The original level of gasoline in the column was restored to an accuracy of $\pm$ 10 ml and the reservoir weight was then measured to an accuracy of 2 gm. The resulting net weight loss of the system was used to determine the average vaporization rate for the one-minute period of bubbling. The circulating, weighing, bubbling, and reweighing processes were repeated to determine subsequent vaporization rates as the supply of gasoline diminished.

Starting with fresh gasoline, (5-gallon supply) the vaporization rate dropped from approximately 175 gm/min (1.5 CFM) to approximately 125 gm/min (1.1 CFM) in the first five minutes. After five minutes the decrease in vaporization rate was more gradual, decreasing to approximately 115 gm/min (1.0 CFM) in the next five minute period.

Based on the vaporization rates shown in Figure 9, and 3% gasoline vapor in fuel/air mixtures, the test mixture velocities were adjusted from approximately 4.3 ft/sec to 2.8 ft/sec. Velocities were determined using the mass conservation equation, as follows:

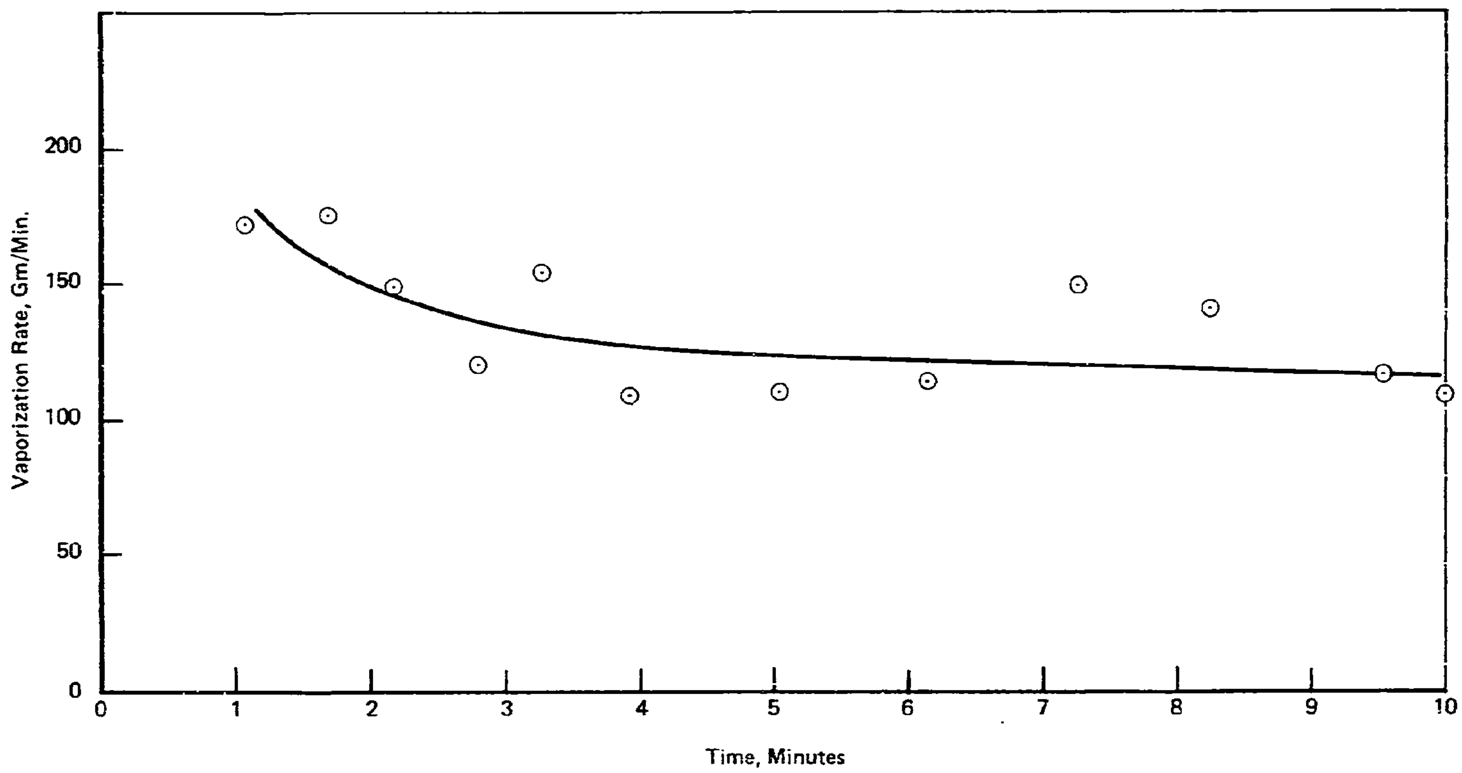

FIGURE 9 CALIBRATION OF GASOLINE VAPOR CONVERTER

$$v = 3.67 \times 10^{-5} \frac{\dot{m}_v}{\rho_v A F}$$

where

v = mixture velocity in the test pipe, ft/sec

$\dot{m}_v$ = vaporization rate, gm/min

ρ_v = gasoline vapor density (0.255 lb/ft^3 at 70°F)

A = cross-sectional area of test pipe (.196 ft^2)

F = fuel fraction (.03) at stoichiometric

3.67×10^{-5} = constant accounting for weight and time conversions.

B. Operating Procedure

In conducting a test, the following sequential procedure was followed:

(1) The arrestor element was installed in the housing (after it had previously been prepared for testing) and the housing cover was secured.

(2) A safety check of the test site was made which included:

- Access to fire extinguishers
- Wearing of hard hats, glasses and ear protection
- Locating danger warnings and restricted area barriers
- Turning on flashing red lights in critical area of the test site.

(3) A check of the optical detector and pressure detector battery condition was made.

(4) The main Power Switch was turned on.

(5) The recorder power and optical, pressure detector power, switches were turned on ignition power and DVM power.

(6) The selection of upper or lower ignition source was made.

(7) Fuel supply and inline heaters were activated and allowed to come to equilibrium temperature, approximately 100°F and 120°F, respectively. For tests with gasoline vapor, the converter was heated to equilibrium temperature without N_2 flow. Then nitrogen was passed through the generator for one-minute.

(8) The air blower was turned on and adjusted to achieve the appropriate flow rate--corrections to the flow rate for barometric pressure and air temperature were made, based on the manufacturer's operating instructions.

(9) Fuel tank valve, fuel shut off cock and solenoid valve were opened. This was followed by an adjustment of the throttling valve until the appropriate fuel flow rate was achieved. Corrections for barometric pressure and fuel gas temperature were also made.

(10) A pneumatic horn signal was given 10 seconds before ignition.

(11) In rapid sequence:

- The recorder chart was turned on (generally to 16-inch/sec speed for adequate trace resolution).
- The ignitor energized--followed immediately by combustion.
- The recorder was turned off (after approximately 1-second).

(12) The fuel solenoid valve was switched to the closed position (if it had not been shut by the photodetector automatically), within one-second on upstream tests and within 5-seconds on downstream ignition tests. For gasoline vapor tests, the nitrogen carrier flow was shut off. Otherwise a standing flame could damage the arrestor or the instrumentation.

(13) The manual fuel flow throttling valve was then shut off within 5-seconds of spark discharge.

(14) The air blower was shut off.

(15) The recorder trace was examined for evidence of flame through, flame speed, and combustion pressure (see Section II C below).

C. Data Acquisition

Figure 10 is an illustration of the typical data obtained from the recorder. The explanation of the trace is as follows:

Trace A: The length of the 60-cycle trace indicated the time interval that the ignition source was energized.

Trace B: The 60-cycle portion indicates that the fuel solenoid valve is open, the steady portion of the right of the 60-cycle trace indicates automatic solenoid shut off or flame-through.

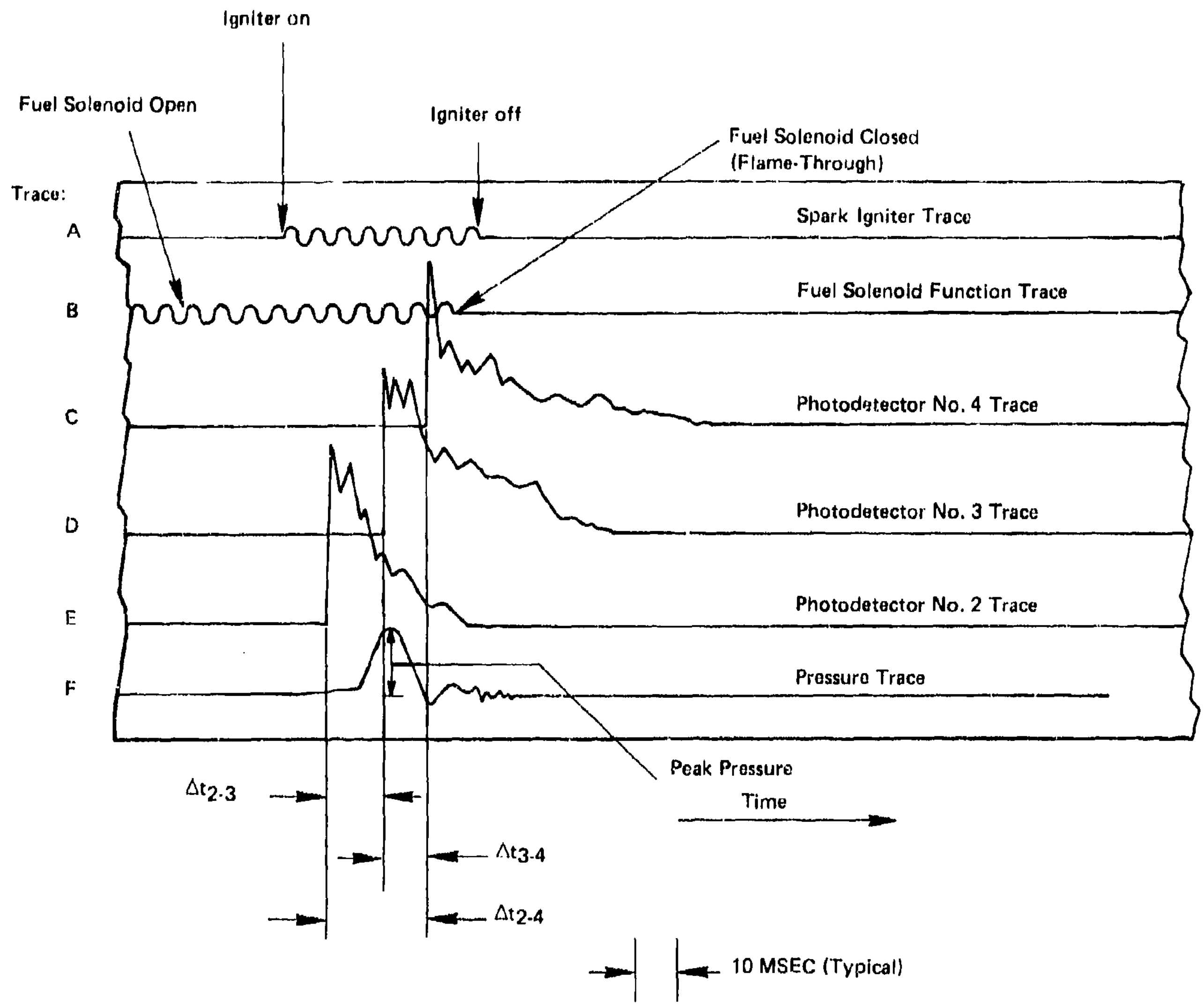

FIGURE 10 TYPICAL TEST DATA RECORDING

Traces C, D and E: Flame passage traces from optical detectors 4, 3, and 2 respectively (Typical). The distances between detectors is known and thus flame velocity between these points are determined (also flame acceleration).

Traces F: Instantaneous pressure trace - for the subject tests, the peak value of the trace was converted to peak pressure by a calibration.

D. Gas Mixtures Tested

Gas mixtures tested during Tasks IA and I were as follows:

- Methane C.P., 99.0% minimum purity, Matheson size 1A 300 ft^3 tank, specific volume 23.7 ft^3/lb, cylinder pressure 2265 psig @ 70°F.
- n-Butane, C.P., 99.0% minimum purity, Matheson size 1F, 136 lb/tank, specific volume 6.9 ft^3/lb, cylinder pressure 21.4 psig @ 70°F.
- Gasoline vapor, Exxon and Mobil Regular, evaporated @ 110°F through 3-3/4 inch dia x 22 inch high packed column using 120°F N_2 gas as carrier medium. Approximate vaporization rate was 2.8 to 4.3 ft^3/min.

E. Flame Arrestors Tested

Descriptions of the flame arrestors that were tested during Tasks IA and I are given in Table 2.

A special fixture was fabricated to enable the parallel plate and crimped ribbon arrestors to be positioned inside the Varec 50SG housing for testing. The fixture consisted of a reinforced base plate and a hold-down frame. In practice the parallel plate arrestor was positioned on the base plate and the hold-down frame placed over the arrestor was bolted to the base plate. All remaining gaps in the assembly were taped to prevent flame by-pass. An exploded view of the

Table 2

Summary of Flame Arrestor_ Tested

Task	Type	Figure	Source	Dimensions	L (in)	D_H (in)	L/D_H	Remarks
IA	Parallel Plate	11(a)	Arthur D. Little, Inc. Experimental design.	11-1/2" x 11-1/2" x 1.06", .048" steel plates with .022" gap	1.06	.031	34	Extra supports were required to maintain plate parallelity
IA	Parallel Plate	11(b)	Arthur D. Little, Inc. Experimental design.	11-1/2" x 11-1/2" x .5", .048" steel plates with .032" gap	.50	.045	11.1	Same as above
IA	Crimped Ribbon	12	Arthur D. Little, Inc. Experimental design.	9" dia x .5" high, half hex crimp .002" foil x .031" hex height, stainless steel	.50	.035	14.3	
IA	Crimped Ribbon	12	Arthur D. Little, Inc. Experimental design.	9" dia x 0.375" high, half hex crimp, .002" foil x .031" hex height, stainless steel	.375	.035	10.7	
I	Single layer screen	13	M.S. Tyler, Inc.	11-1/2" x 11-1/2" 30 mesh x .011" wire dia, steel	–	.022	–	
I	Corrugated channel	14	Varec Inc.	13-1/2" x 13-1/2" x 6-1/2", Model 50 SG series, cast iron frame, aluminum bank assembly, 6" size, 150 lb ASARE flanges	5.75	.077	87	

Table 2 (continued)

I	Crimped ribbon	15	Amal Ltd	9-1/2" dia x .75" high, Model 188/905/75/24/CN, tri-angle crimp .024" high	.75	.021	35.7
I	Crimped ribbon	16	Amal Ltd	9-1/2" dia x 1.5" high, Model 188/905/15/45/CN, tri-angle crimp .045" high	1.5	.038	39.5
I	Crimped ribbon	17	Shand & Jurs Co.	Model 94305-16-11, 6" size, aluminum, 13" dia x 6" high	6.0	.045	133
I	Parallel plate	18	Protectoseal Co.	Model 4956-36, alu-minum plates - 8-3/4" O.D. x 6" I.D. x .093" thick with .031" gap	1.38	.043	32
I	Double screen	19	Press-Vac Eng. Ltd.	Model PL-6, 2 screens 8-1/2" dia, .6" apart. Screens 20 mesh x .01" wire diameter	-	.04	-
I	Metal foam	20	Retimet	Grade 30, .28" thick, 33 pores per inch	0.28	.030	9.3

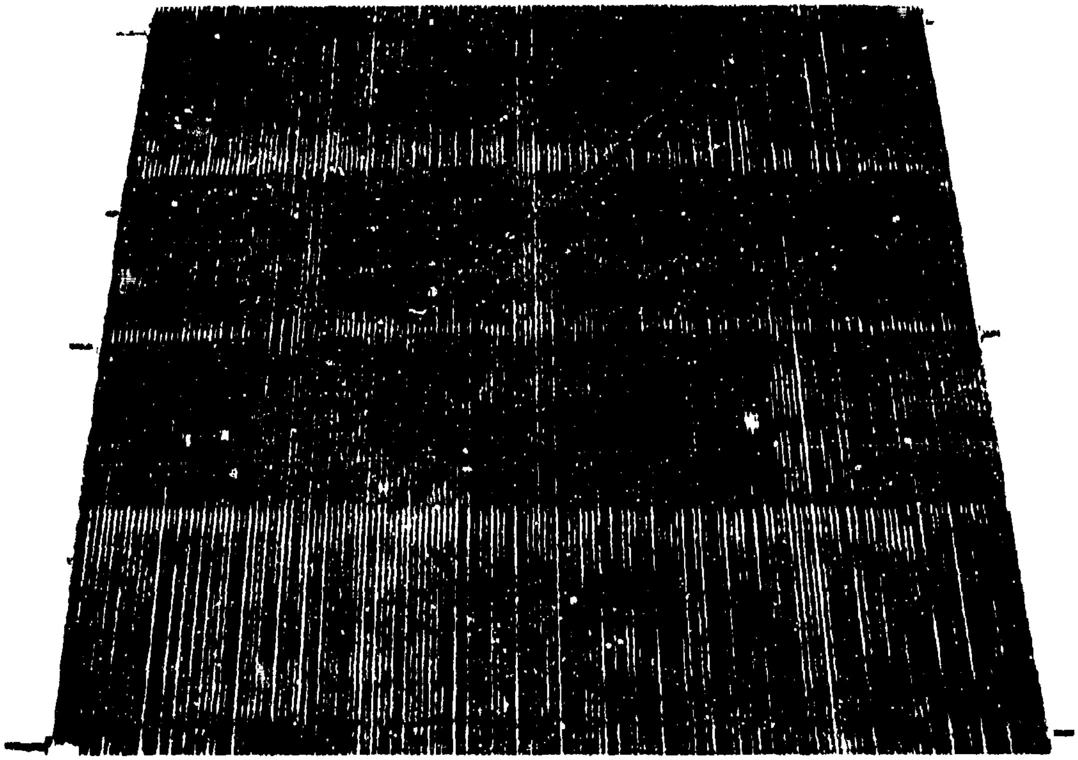

Figure 11a: Parallel plate arrestor (.022" gap, 1.06" depth)

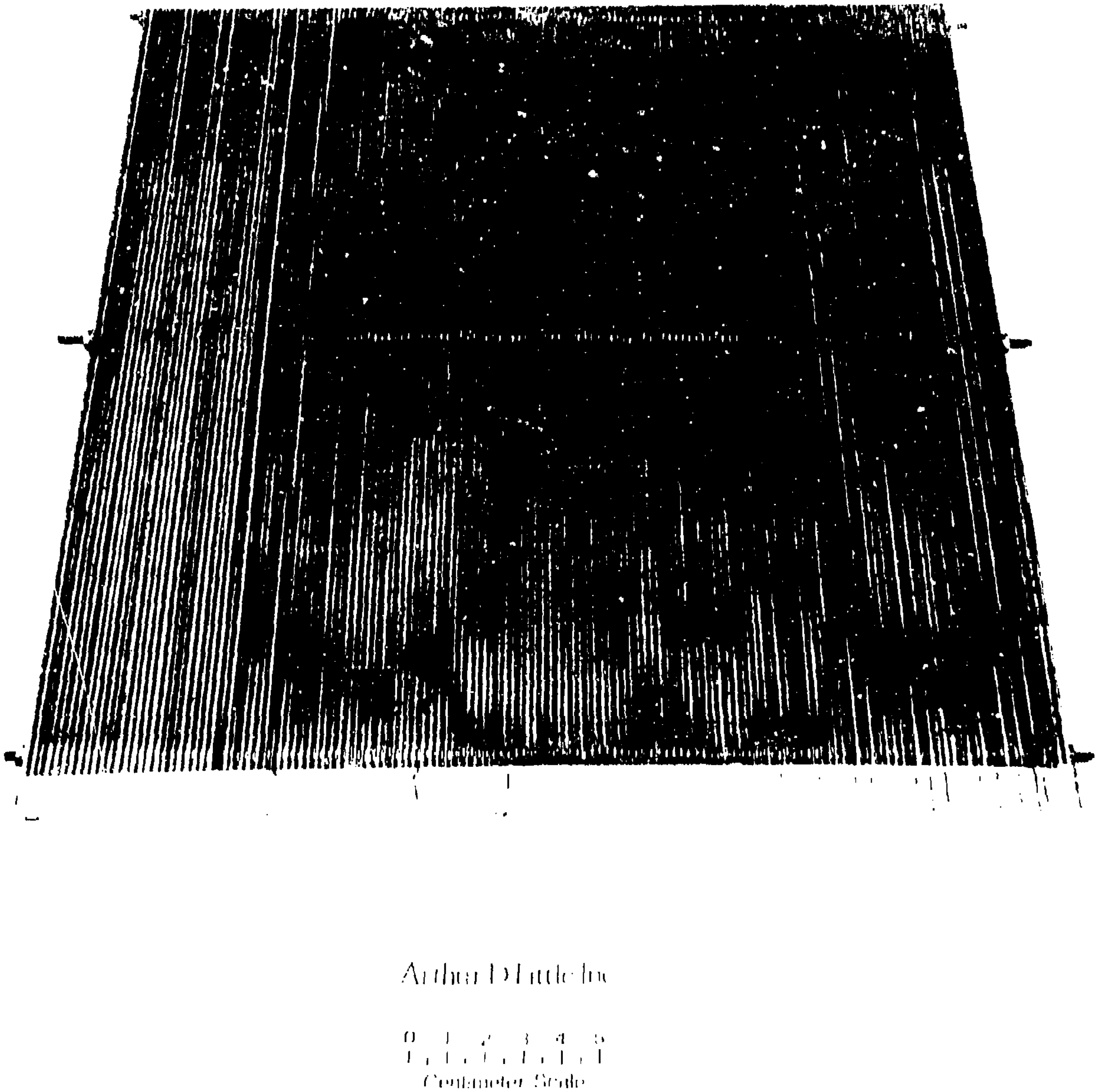

Figure 2: Parallel plate arrester (.032" gap, 0.[illegible]" depth)

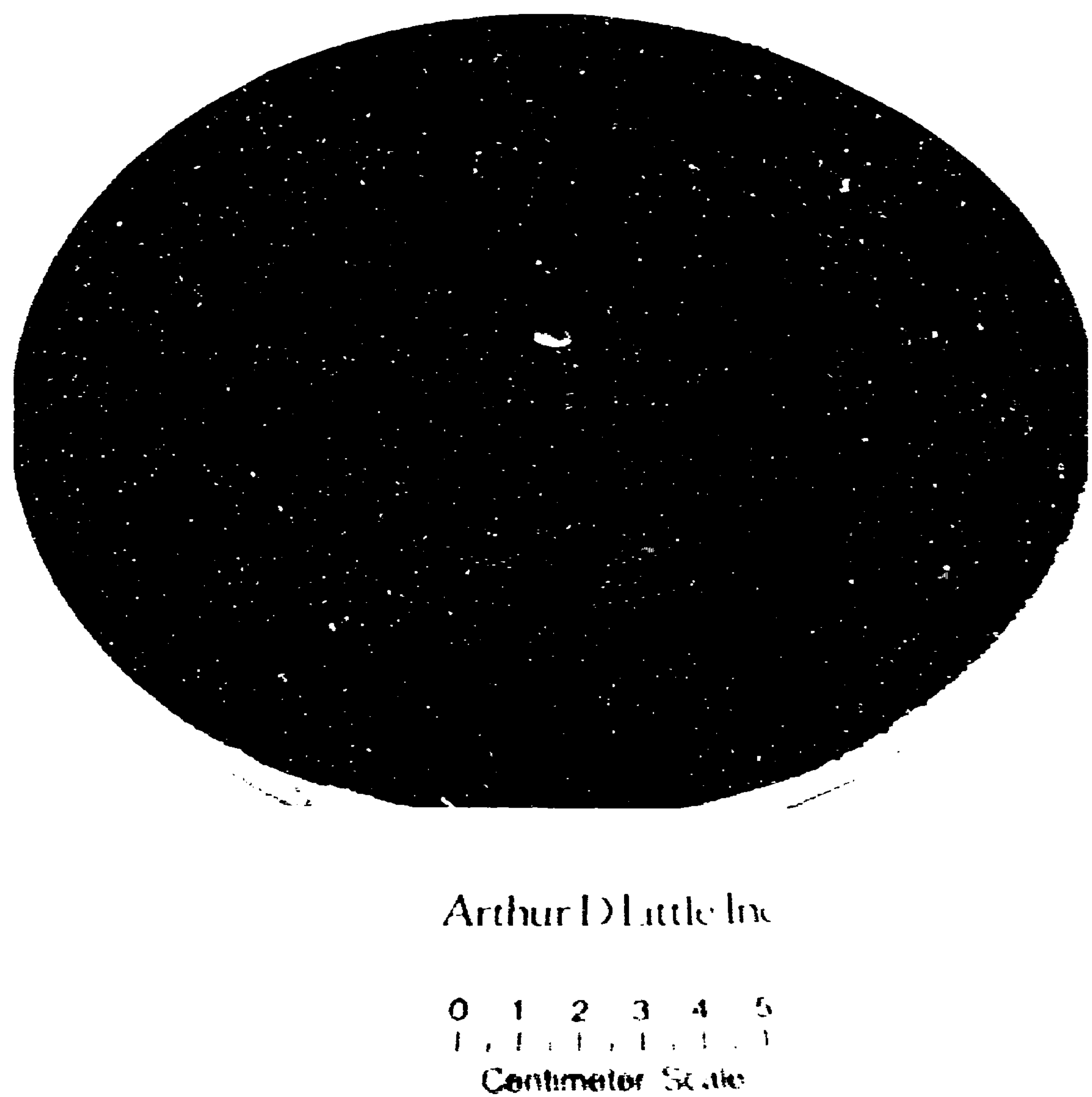

Figure 8: Crimped ribbon arrestor (.031" hex height)

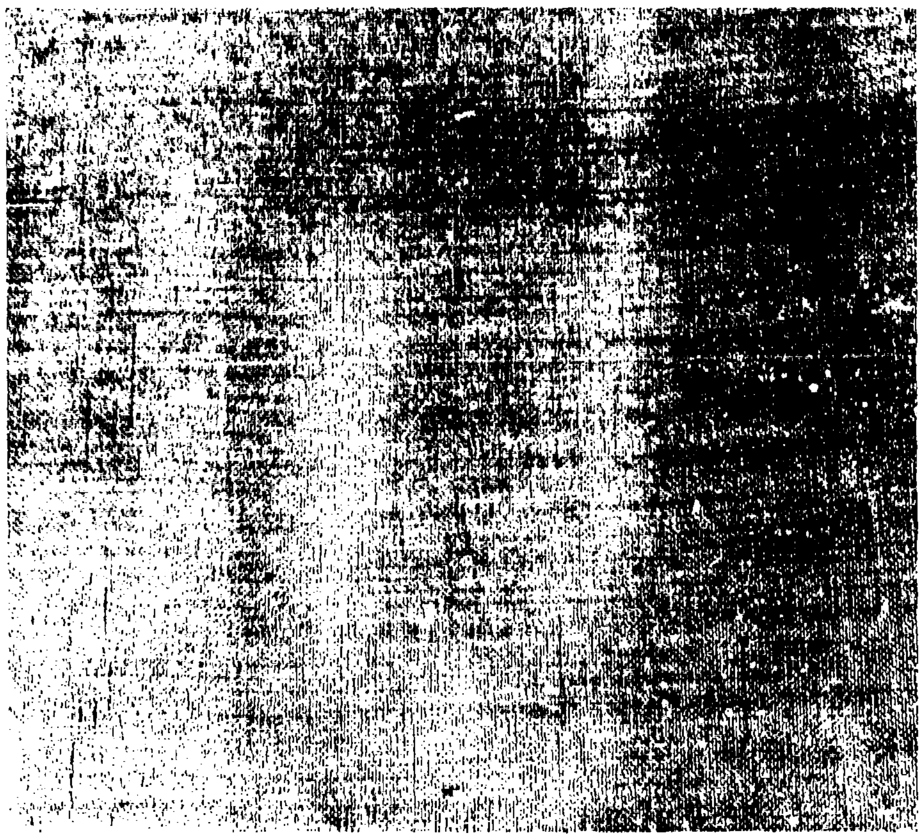

Figure 13: Single layer screen arrestor
(30 mesh x .011" wire dia.)

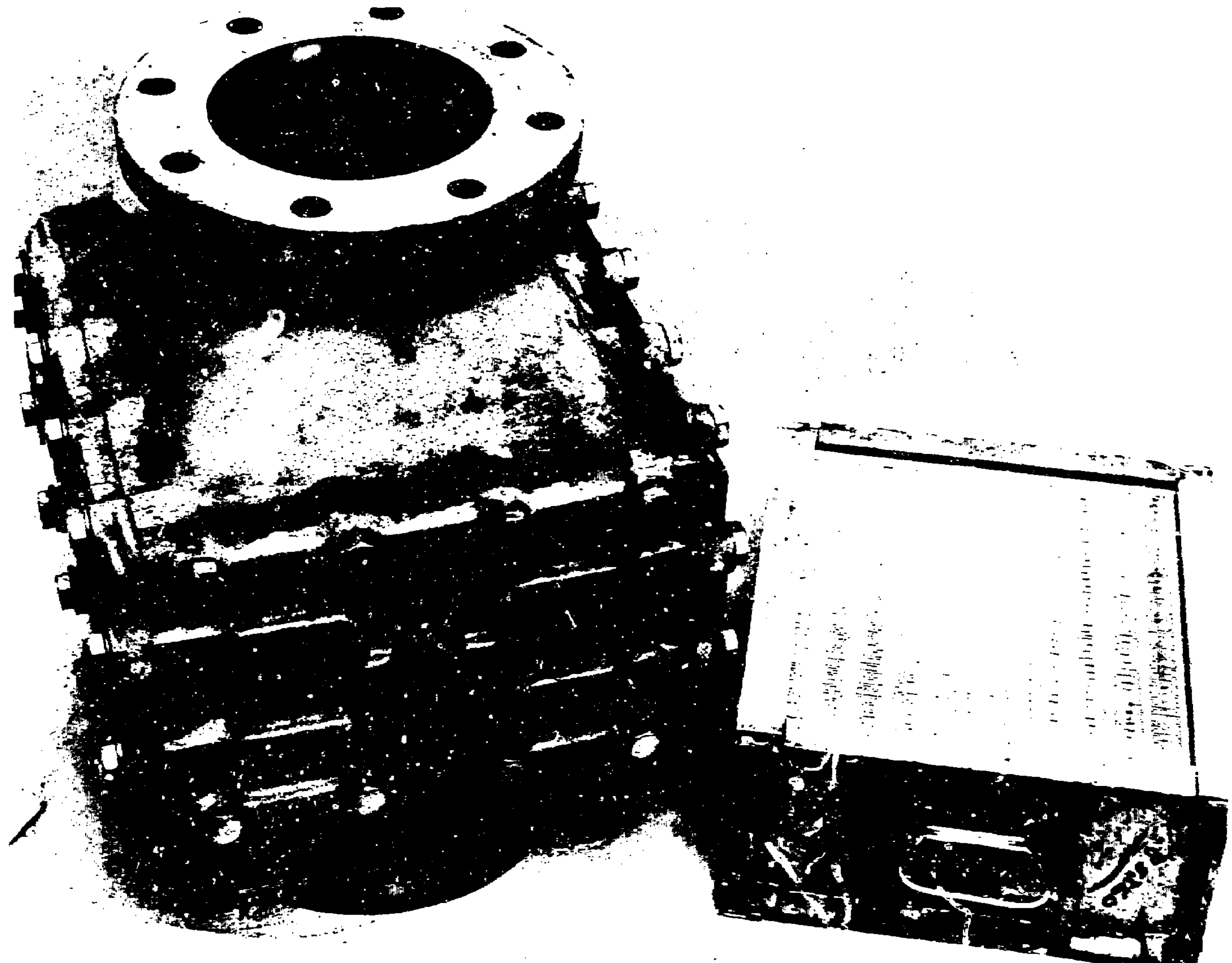

Figure 14: Corrugated parallel plate arrestor (Varec Model 50 :G)

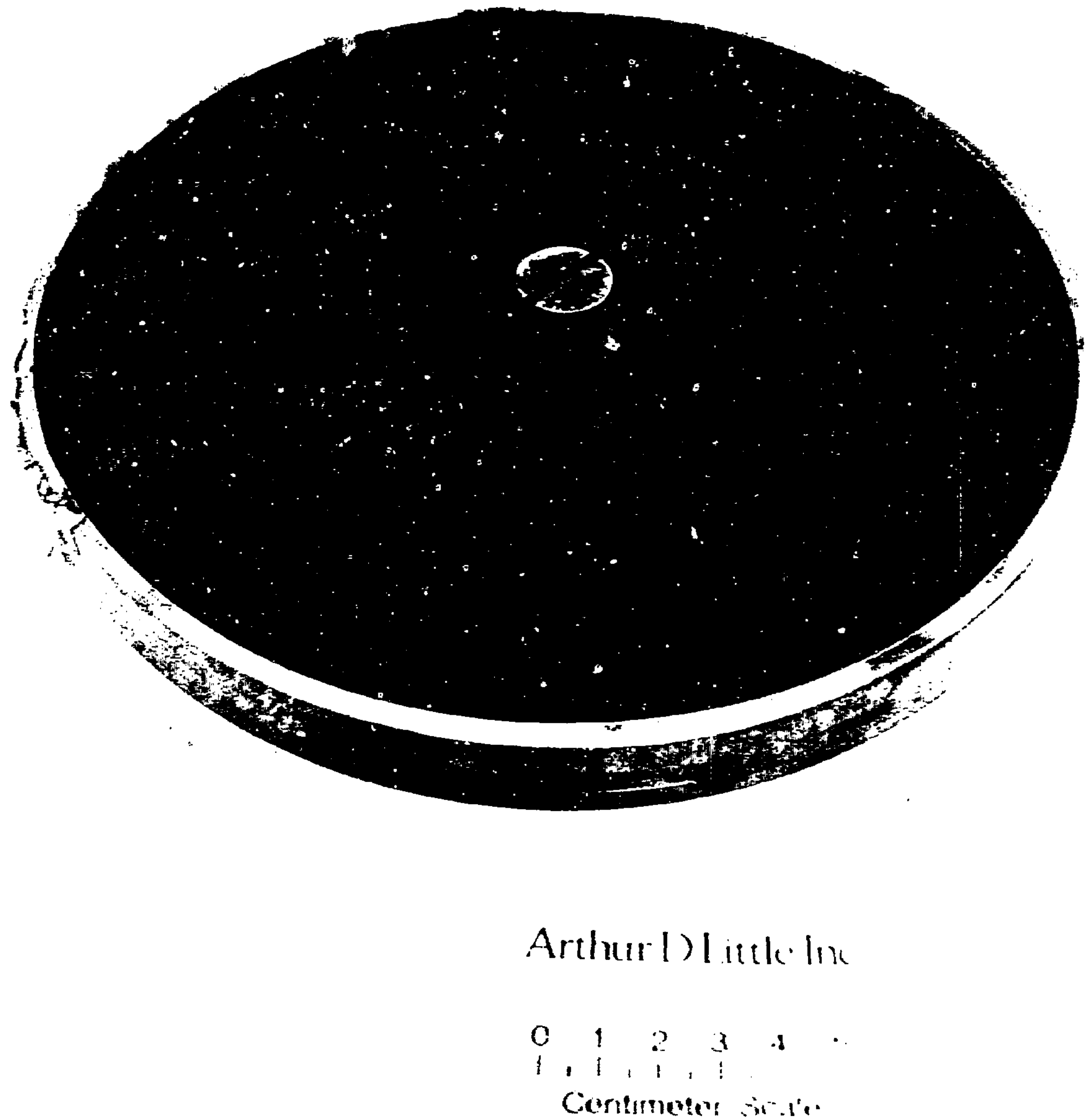

Figure 15: Crimped ribbon arrestor (Amal Ltd., .024" crimp)

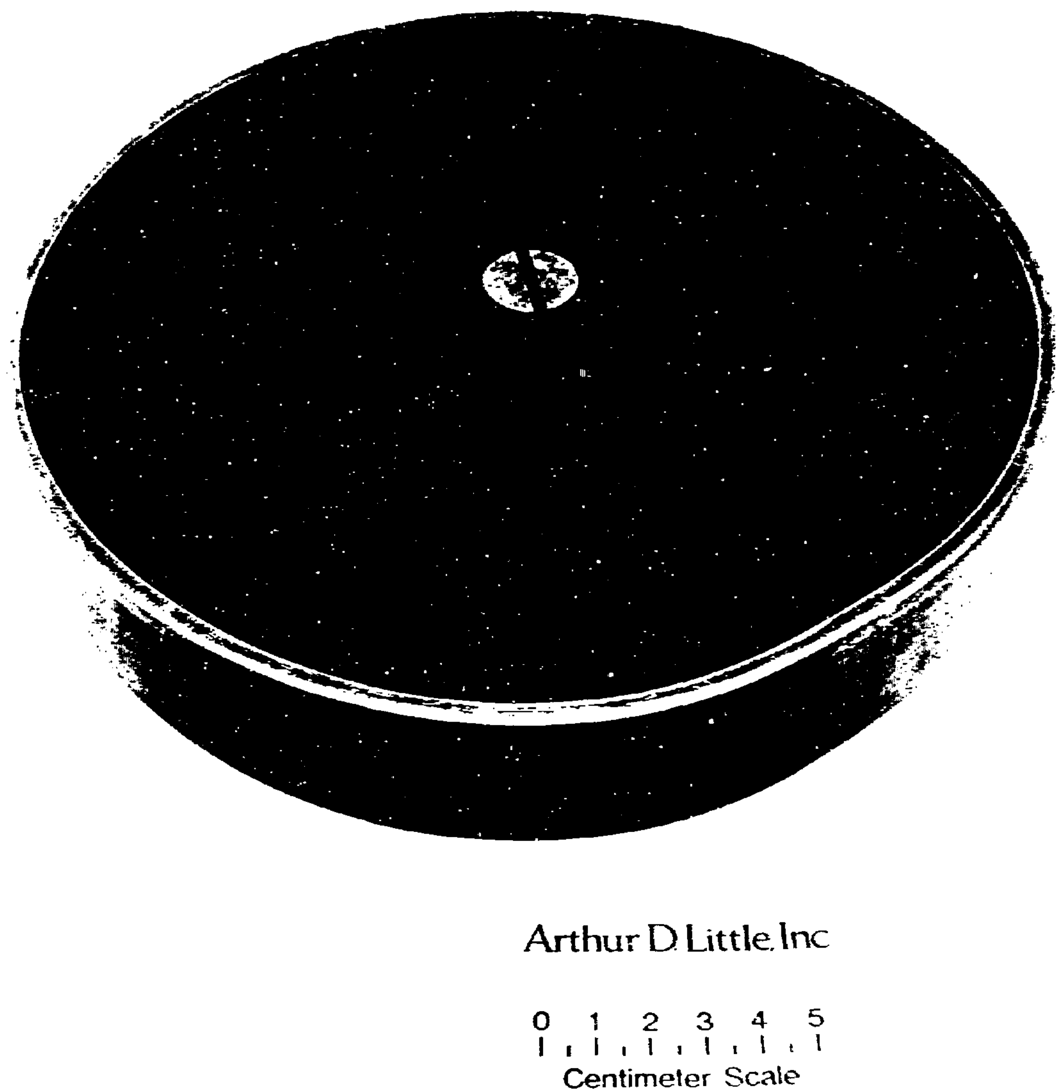

Figure 16: Crimped ribbon arrestor (Amal Ltd., .045" crimp)

Figure 17: Crimped ribbon arrestor (Shand & Jurs)

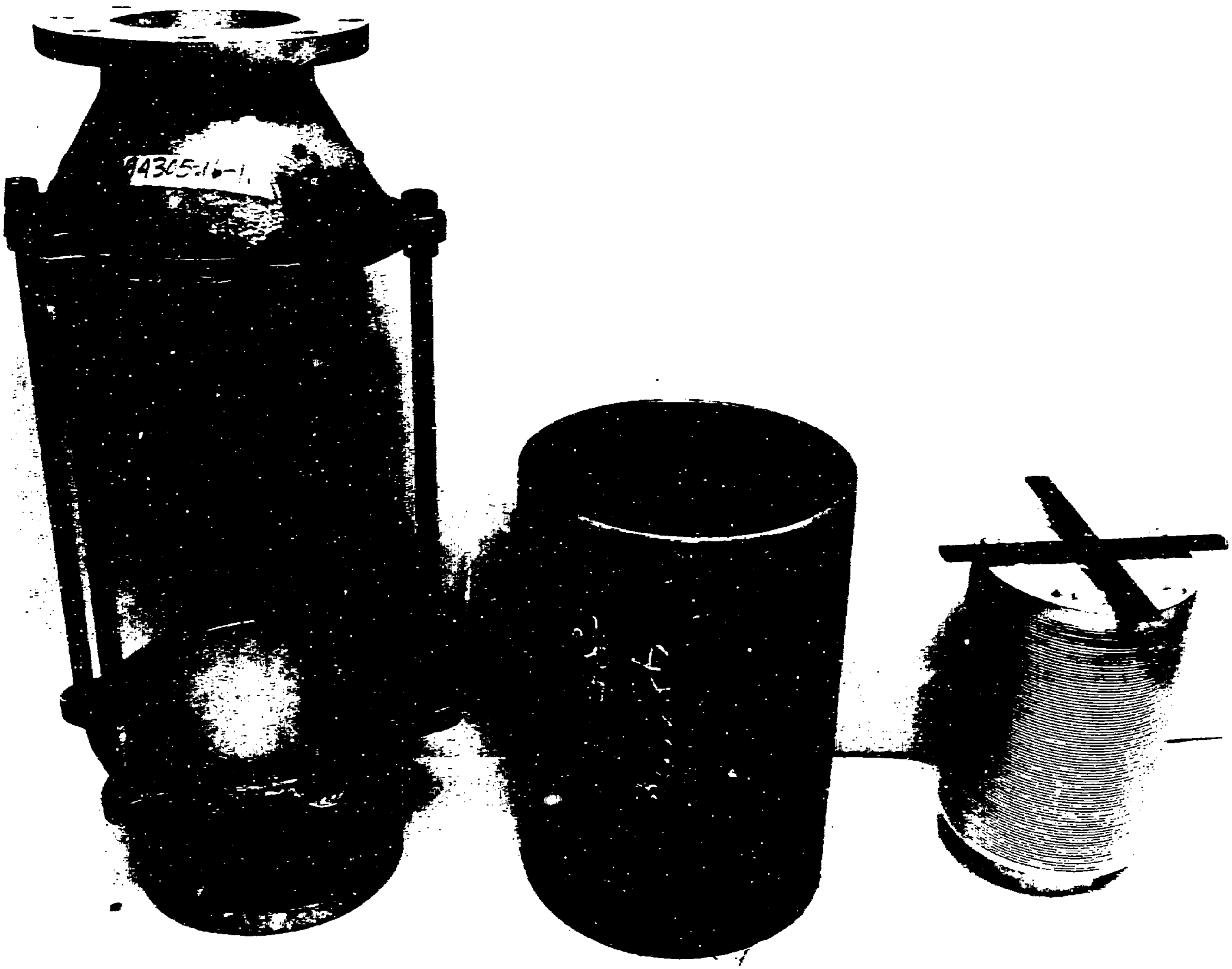

Figure 18: Parallel plate arrestor, radial flow (Protectoseal, .031" gap)

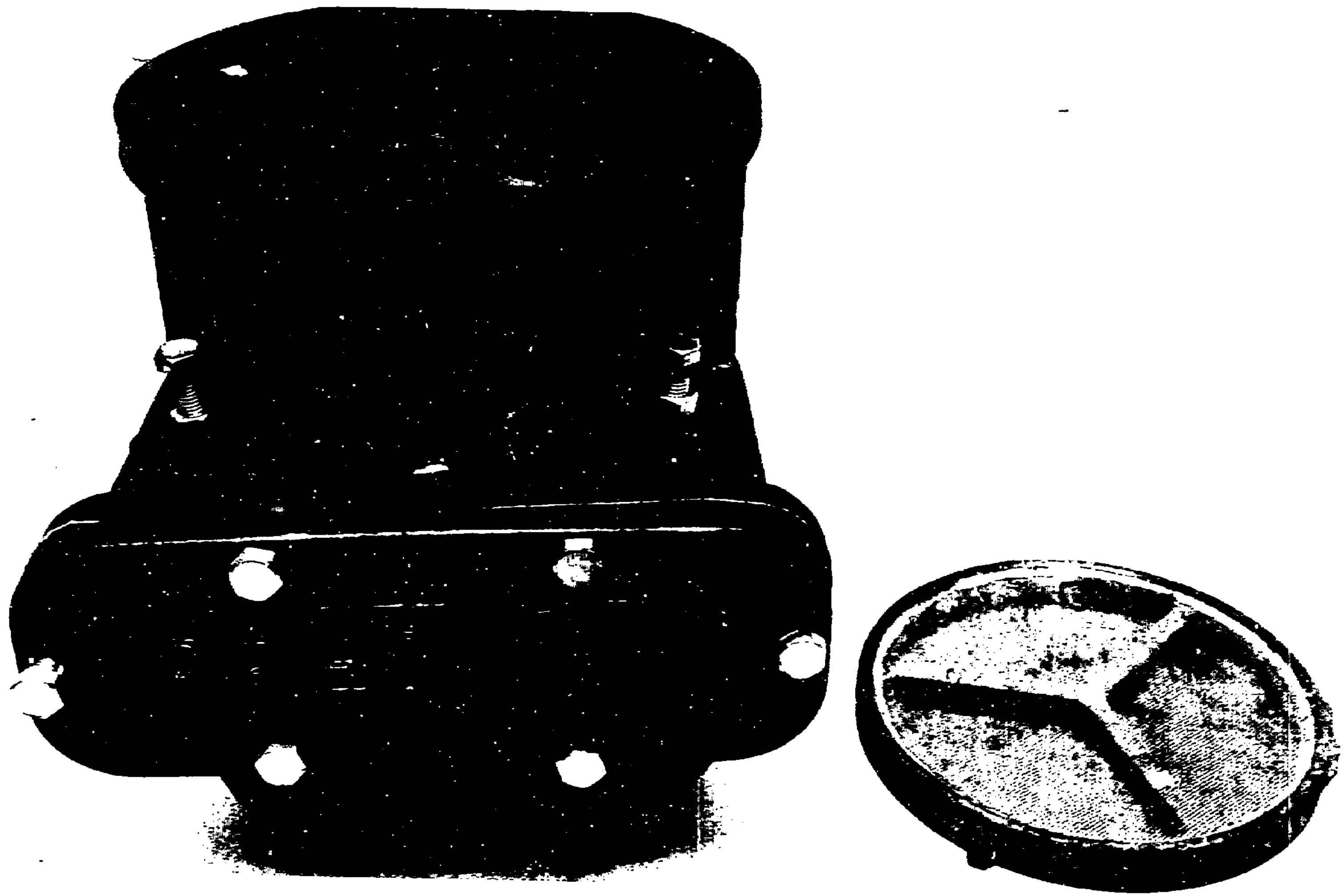

Figure 19: Double screen arrestor (Press-Vac, 20 mesh)

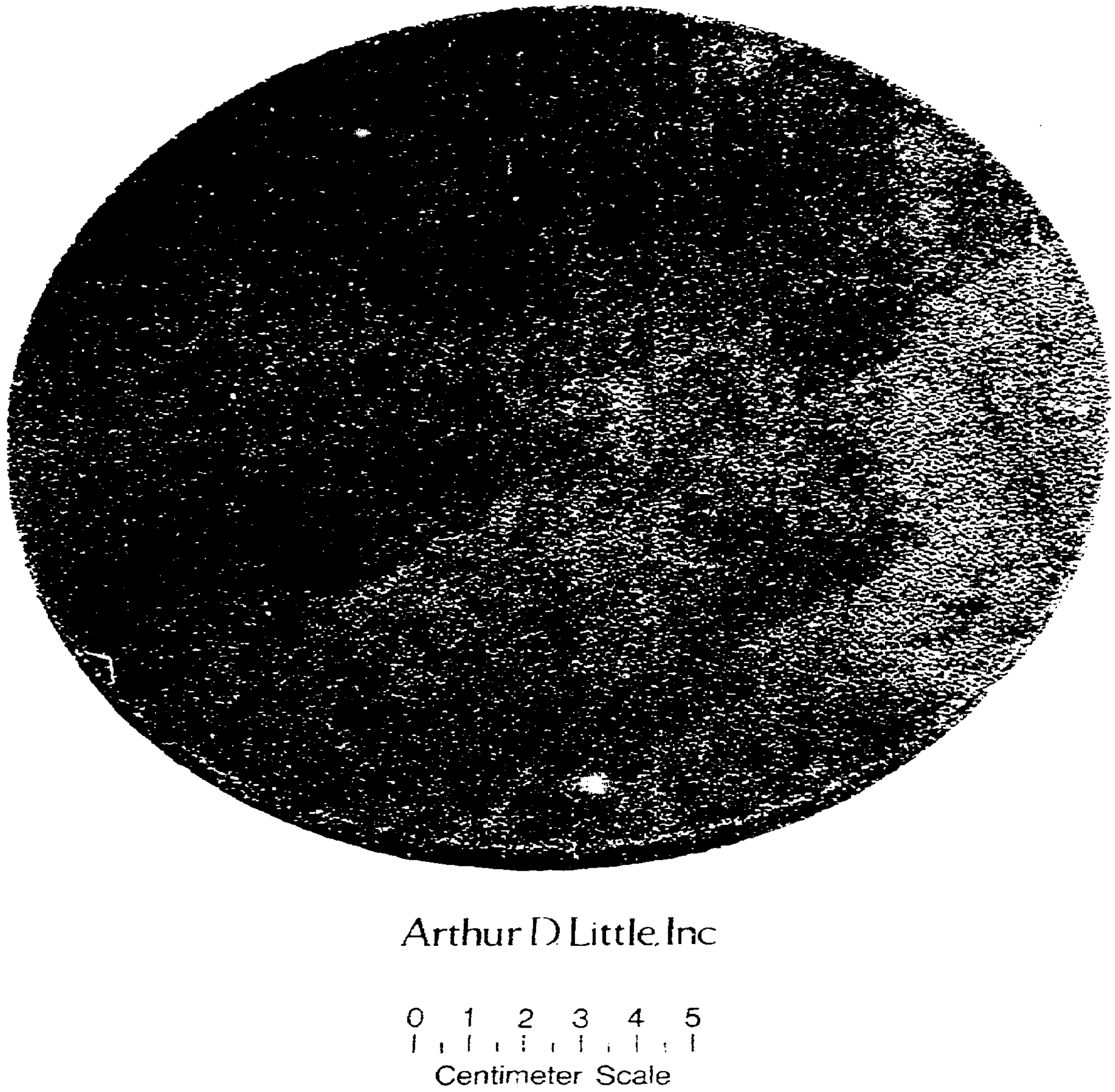

Figure 20: Retimet grade 3 arrestor

fixture is shown arranged to accommodate the Amal arrestor in Figure 21. The base plate assembly was used to test the following arrestors:

- Experimental crimped ribbon
- Experimental parallel plate
- Single screen
- Amal crimped ribbon
- Retimet metal foam

In preparing the 9" diameter crimped ribbon arrestors for tests, a 11-1/2 inch square piece of 6-mesh screen was first placed onto the base plate. Then the arrestor was placed on top of the hole in its center (6 lb density loCon insulation) was packed around the arrestor to fill the open volume between the periphery of the arrestor and the base plate. An 8-1/2" diameter piece or mesh screen was placed on top of the arrestor and a sheet metal plate 11-1/2 inch square housing a 8-1/2" diameter hole in its center was placed over the arrestor. The hold-down frame was then placed on top of the assembly and bolted to the base plate. All other openings were sealed to prevent flame by-pass.

Tests on the single screen and the Amal crimped ribbon arrestors were performed using the Varec arrestor housing adapted to permit the installation of various arrestor elements. During their respective tests, both screen and Amal were mounted in the universal base-plate assembly and installed into the Varec housing. Figure 4 illustrates the arrangement in which the arrestor elements were installed in the Varec arrestor housing. The figure shows the arrestor arranged for upstream ignition tests (flame propagating up from below).

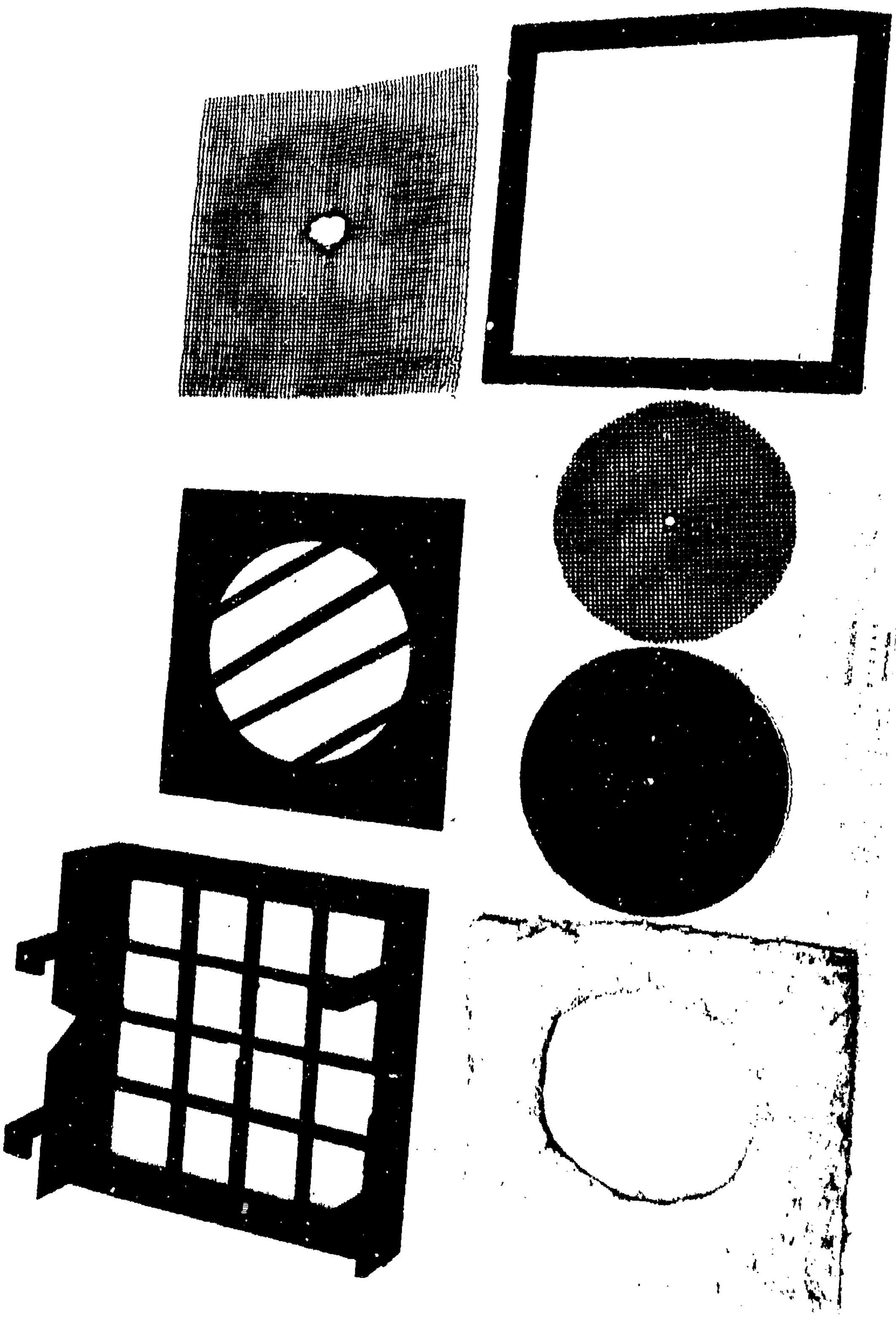

Figure 21: Base-plate assembly arranged for Amal arrestor

III. EFFECT OF MIXTURE SPEED AND IGNITER LOCATION ON ARRESTOR PERFORMANCE

A. Purpose of Tests

The purpose of Task IA was to conduct a systematic investigation of the effects of gas/air mixture speed and ignition-source location on the flame speed and arrestor performance. The data was used to determine a set of worse case conditions for testing commercial arrestors in the ADL apparatus.

B. Effect of Mixture Speed (Downstream Ignition)

The effect that mixture velocity has on flame speed was investigated using both butane and methane gas/air mixtures. The investigation consisted of a series of flashback tests at various mixture velocities ranging from approximately 2 ft/sec to 16 ft/sec. A 3" diameter orifice was used behind the ignitor to accelerate the flame in all tests (see Figure 3). Ignition of the gas mixture took place 67" downstream of the arrestor. The flame propagated upstream. The flame speed, approaching the arrestor, was determined from the output signals of three photo-detectors located in the upper test pipe (2", 17" and 41" from the arrestor base-plate). For these tests, a parallel plate arrestor of dimensions L = 1.0" and D_H = .031" (see Figure 11) was used to quench the flames. Fuel/air mixtures were adjusted at each velocity to an equivalence ratio of $\phi = 1.1$ which has been shown to give the maximum flame speed.

For butane/air mixtures, flame velocity relative to the arrestor decreased from approximately 125 ± 75 ft/sec to 30 ± 20 ft/sec as mixture velocity increased from 2 ft/sec to 18 ft/sec. Above 18 ft/sec mixture velocity, flames failed in most cases to propagate upstream. The effect is shown in Figure 22. Complete test results are tabulated in Table A-1 of Appendix A.

Tests using methane/air mixtures indicated that the approach flame speed is constant at 140 ± 15 ft/sec regardless of mixture speed over the range 2 to 19 ft/sec.* The effect is illustrated in Figure 23. Velocities based on photodetectors 3-4 were consistently higher than

*On certain tests (e.g., 012177-8) the photodetector trace was irregular; however on the majority of runs the flame speed was approximately 140 ± 15 ft/sec.

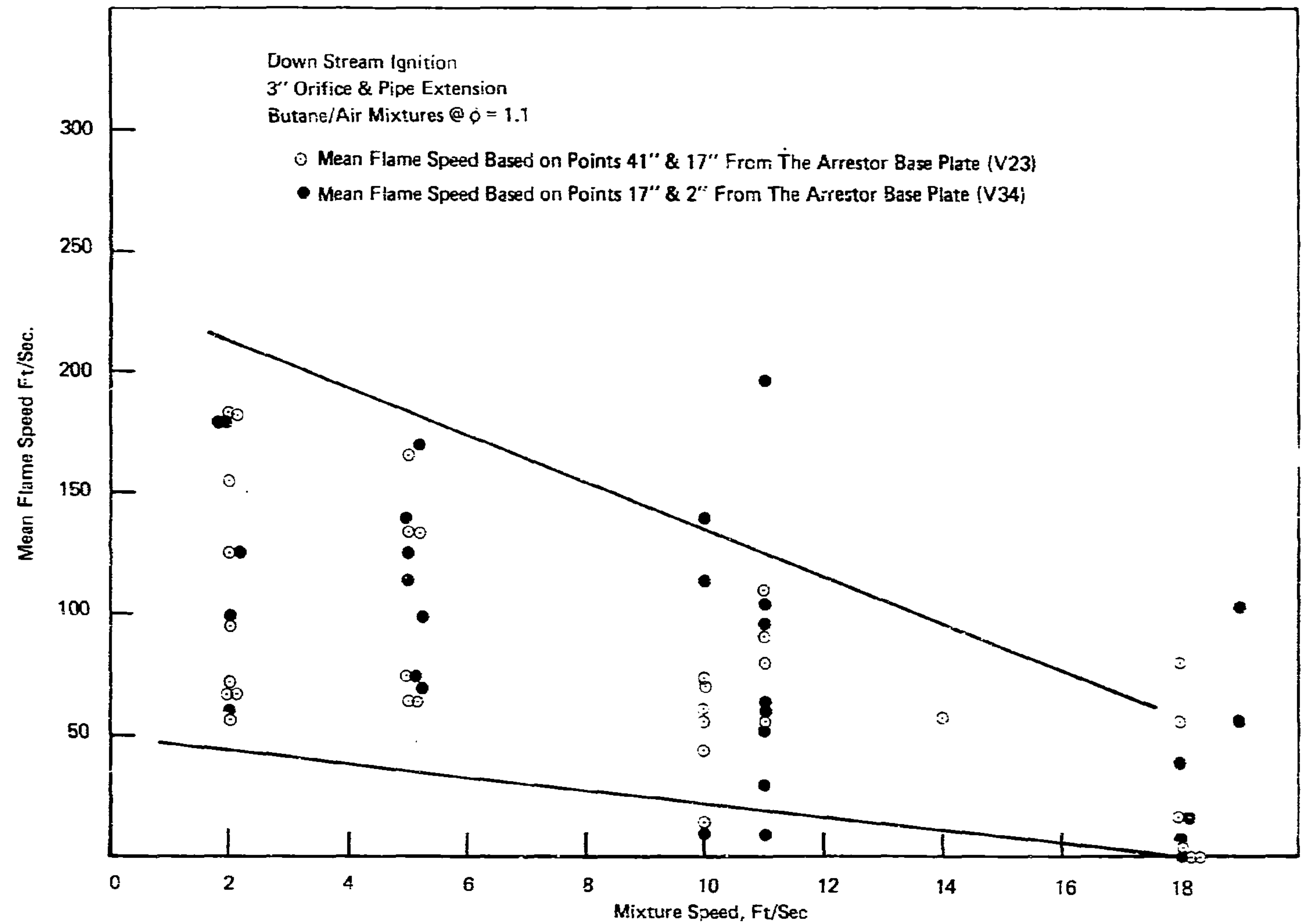

FIGURE 22 EFFECT OF MIXTURE SPEED ON FLAME SPEED

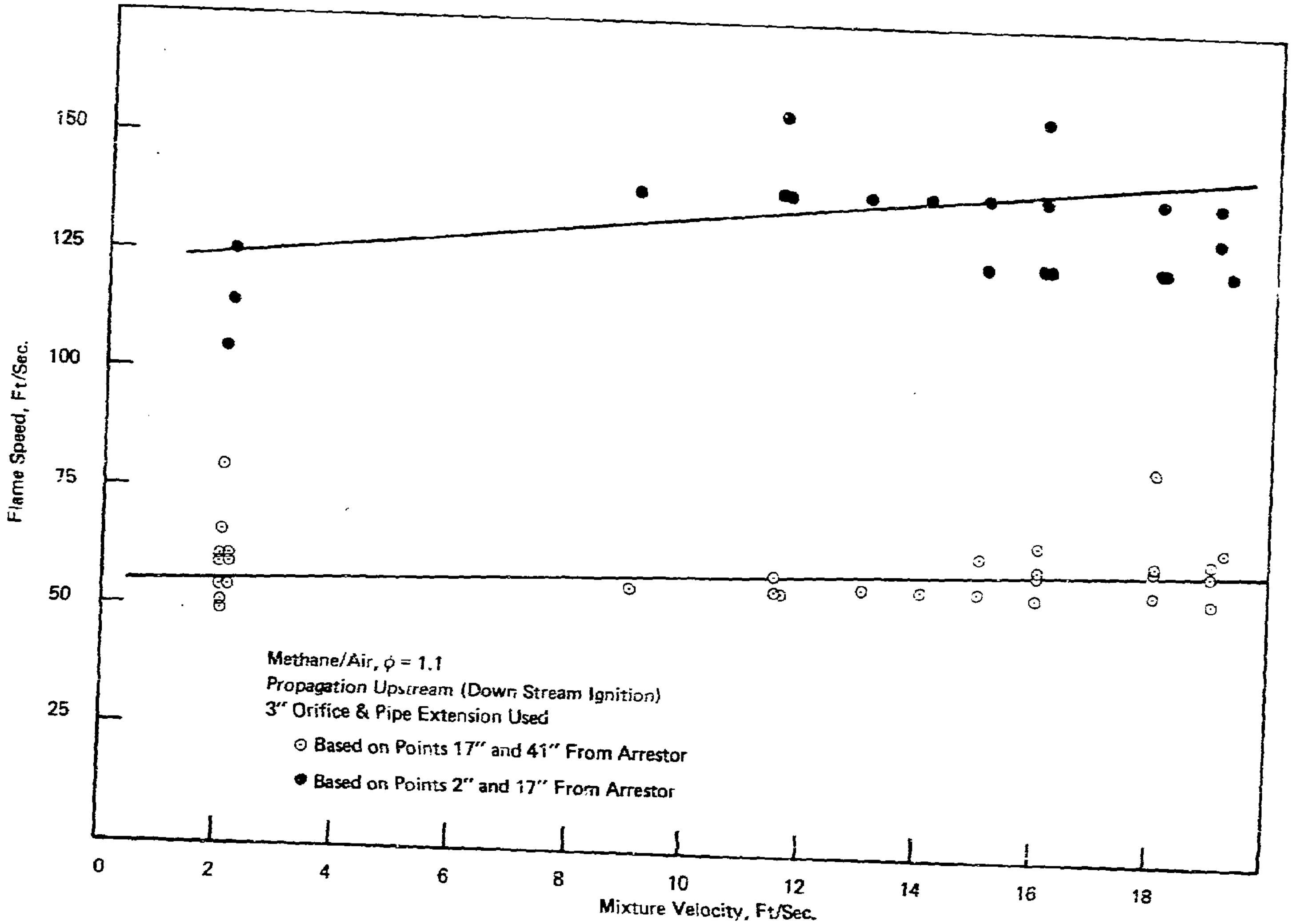

FIGURE 23 EFFECT OF MIXTURE SPEED ON FLAME SPEED

those for detectors 2-3 and therefore indicate a consistent acceleration of the flames using methane. The acceleration of the butane flames was not clearly defined because of the wide scattering in the measured flame speed. The source of this scatter is believed due to the irreproducible ignition process with butane/air flames; i.e., each ignition produces a different flame shape.

In summary, our findings on the effect of mixture speed, for the conditions of downstream ignition (upstream propagation) and a 3" orifice in the line, are as follows:

- For butane/air, the highest flame speeds (125 $\pm$ 75 ft/sec) are achieved with mixture velocities near 2 ft/sec.
- For methane/air, approach flame speeds are 140 $\pm$ 15 ft/sec, apparently independent of mixture speed.
- For butane, mixture velocities somewhat above 18 ft/sec are sufficient to prevent upstream propagation of flames (for this particular ignition geometry which incorporates a 3" diameter orifice and an 18" long extension tube).

C. Critical Mixture Velocity Which Allows Upstream Flame Propagation

Tests with both methane/air and butane/air mixtures were performed to determine the highest mixture velocity that will allow upstream flame propagation. It is recognized that whether a flame can propagate upstream depends on the ignition conditions (location of ignitor with respect to pipe exit, constriction at the pipe exit, etc.). In these tests, the 3" diameter orifice was removed to minimize back pressures. Ignition of the gas mixtures took place 26" from the pipe exit and, in a second test series, 46" from the pipe exit.

In the tests, failure to propagate upstream was noted by either (a) a "torch effect" in which flames issued from the top of the pipe in a steady state fashion rather than propagating down the test pipe, or (b) a failure to ignite at all.

The results of the tests disclosed that with ignition taking place 26 inches from the exit, the critical mixture velocity to prevent upstream propagation of methane/air mixtures is between 7 and 7.5 ft/sec;

for butene the critical mixture velocity is between 8.2 and 8.6 ft/sec. With ignition occuring 46 inches from the pipe exit, the critical mixture velocity for methane is beyond 19 ft/sec. The above results are summarized below in Table 3. Detailed test data are tabulated in Table A-2 of Appendix A.

D. Effect of Upstream Ignition

As a further investigation to determine worse case conditions for testing arrestors, tests were performed in which gas mixtures were ignited upstream of the arrestor and permitted to propagate downstream. For these tests, the photodetectors, pressure transducer, and ignitor were installed in the lower test pipe in positions approximately similar to their counterpart locations in the upper pipe section. In order to maintain similarity of the testing geometry, the flame arrestor holder (which was specifically made to accommodate various experimental arrestors inside the Varec Model-50SG arrestor housing), was modified so that the arrestors could be installed in an inverted position (see Figure 4). Thus, the geometry of the housing from the test pipe to the arrestor was the same for upstream ignition as for downstream ignition. The 3" diameter orifice remained in position for the upstream ignition tests, 64" downstream of the arrestor housing flanges.

The results of the tests indicated that for butane/air mixtures, flame velocities propagating downstream, taken with respect to the arrestor, increased from 140 $\pm$ 30 ft/sec to 200 $\pm$ 60 ft/sec as mixture velocity increased from 4 ft/sec to 16 ft/sec. The effect is illustrated in Figure 24. The scatter in those results ($\pm$ 60 ft/sec) is attributed to the mixture inhomogeneities reported above (see page 10). A cross check using methane indicated that flame speed was not a strong function of mixture velocity, with an average flame velocity of approximately 200 ft/sec over the range 4 ft/sec to 16 ft/sec. Table 4 summarizes the response of flame speed to mixture speed and spark location. Detailed results are tabulated in Table A-3 of Appendix A.

E. Marginal Arrestor Dimensions (Critical L & D_H) for Quenching Butane & Methane Flames

If the worst case flame conditions (ignitor location and mixture speed) were selected on the basis of highest flame speed, then the

TABLE 3

Conditions for Upstream Flame Propagation

Spark Location	Critical Mixture Velocity Methane/Air	Critical Mixture Velocity Butane/Air
26" inside pipe exit	7 - 7.5 ft/sec	8.2 - 8.6 ft/sec
46" inside pipe exit	> 19 ft/sec	--

All tests run at $\phi = 1.1$, open ended 6" pipe.

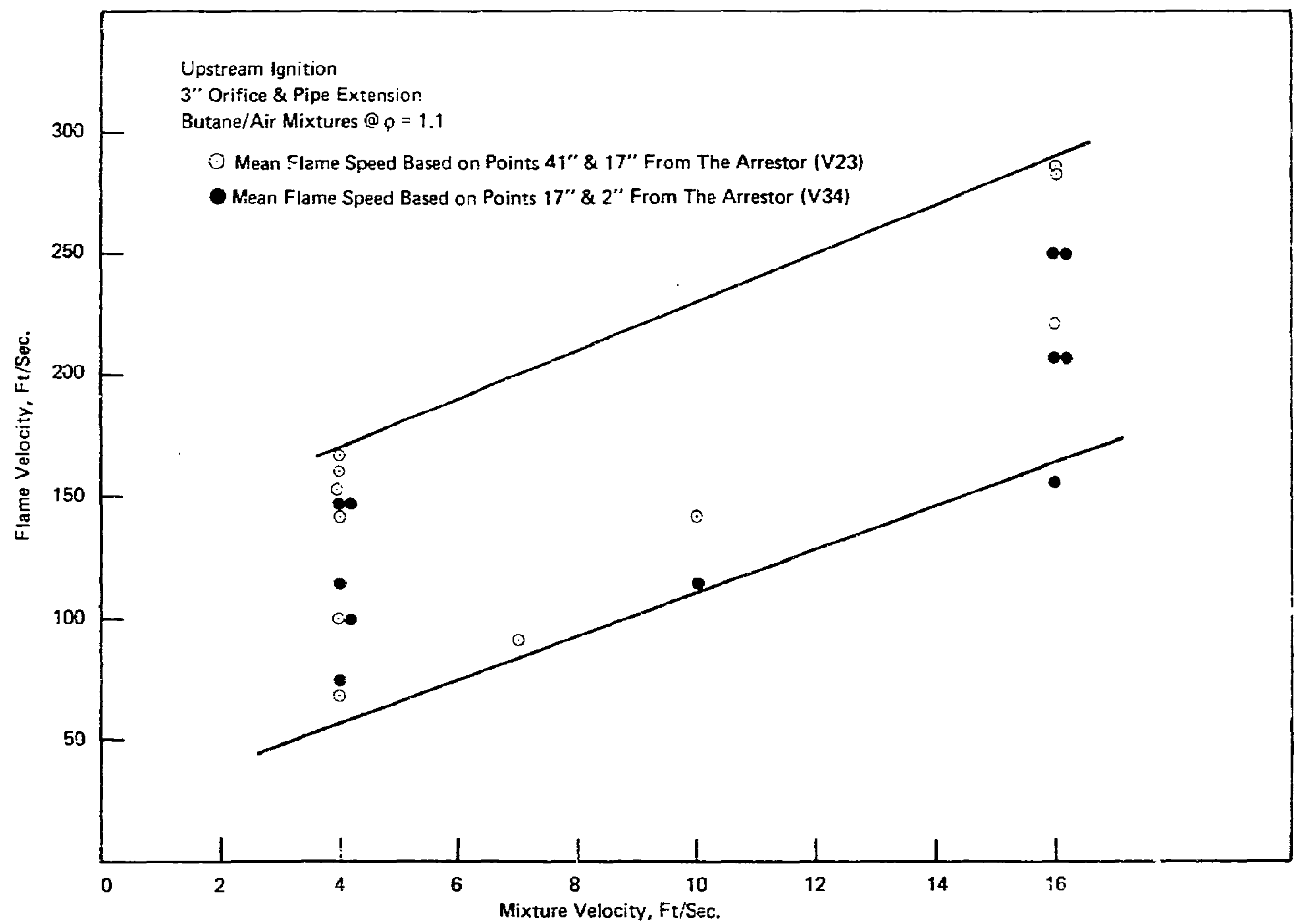

FIGURE 24 EFFECT OF IGNITION LOCATION ON FLAME SPEED

TABLE 4

Effect of Mixture Speed and Spark Location on Flame Speed

Mixture	Upstream Ignition (5.5 ft Run-up; Gas Expansion Restricted by Mixing Tee and Blow-out Pipe)	Downstream Ignition (5.5 ft Run-up; Gas Expansion Restricted by 3" Orifice and 18" Long Extension)
Methane/Air $\phi = 1.1$	Flame speed Constant at 200 ft/sec for all mixture speeds from 4 to 16 ft/sec.	Flame speed constant at 140 $\pm$ 15 ft/sec for all mixture speeds from 2 to 19 ft/sec.
Butane/Air $\phi = 1.1$	Flame speed increases from 140 $\pm$ 30 to 220 $\pm$ 60 ft/sec as mixture speed increases from 4 to 16 ft/sec.	Flame speed decreases from 125 $\pm$ 75 to 30 $\pm$ 20 ft/sec as mixture speed increases from 2 to 18 ft/sec.

results reported above in Section B and D would be sufficient. The highest flame speed for both methane and butane is about 200 ft/sec and occurs with upstream ignition and 16 ft/sec mixture speed.

In order to check that this was indeed the worst case, we tested a "marginal" arrestor under various conditions and observed which conditions would most readily make it fail.

First, we attempted to identify "marginal" arrestor dimensions. A series of tests were performed in which selected arrestors, parallel plate and crimped ribbon types, were tested to determine the combination of hydraulic diameter, D_H, and arrestor length, L, that would successfully quench low speed flames but will fail to quench high speed flames. Methane and butane were used as fuels.

After installing the arrestors, the tests were performed by iteration of the mixture speed: First tests were run at low mixture speed, e.g., 2-4 ft/sec, and it was observed whether quenching took place. If quenching occurred, high-speed mixtures (e.g., 16-15 ft/sec) were ignited and observed for quenching. If quenching occurred at the high mixture velocity, the arrestor was replaced by another whose dimensions were expected to be more marginal, and the above tests repeated. If (with the initial arrestor) quenching did not occur for high-speed mixtures, tests were performed at lower mixture speeds (e.g., 8-10 ft/sec) and the process of testing alternatively at higher and lower mixture speeds was repeated until a mixture speed was arrived at where the arrestor performance was marginal.

Two experimental parallel-plate arrestors, fabricated by ADL from .048" thick steel plates, 11-1/2 inches square were used: One having dimensions L = 1.0" and D_H = .031" (Figure 11a), the other having L = 0.5" and D_H = .045" (Figure 11b). In addition, two crimped ribbon arrestors fabricated from materials supplied by Ferrotherm Corporation were used, one having L = 0.5" and D_H = .035"; the other having L = 0.375" and D_H = .035" (Figure 12).

The critical dimensions just sufficient to quench flames of moderate speed propagating in methane/air and butane/air mixtures were found

to be L = 0.5" and D_H = .045" for parallel plates and L = 0.375" and D_H = .035" for crimped ribbon.

F. Compatibility of the Test Apparatus with Pressures Generated During Tests

During most of the flame arrestor tests, pressure excursions in the pipe interior were recorded. The peak pressures, often an isolated spike, varied from approximately a minimum of 5 psig to near 50 psi maximum as test conditions varied. An average of peak pressures was noted to increase approximately as flame speed increased, e.g., 20 psig @ 25 ft/sec to 40 psig @ 350 ft/sec. Since no damaging effects have been observed as a result of pressure rises, the system is considered to be safe.

G. Selection of "Worst Case" Condition

On the basis of flame speed alone (See Table 4), the "worst case" set of test conditions is upstream ignition at a mixture velocity of 16 ft/sec for both butane and methane gas/air mixtures, adjusted to an equivalence ratio ϕ = 1.1.

This choice was validated by tests on the "marginal" arrestors identified in Section E. As shown in Table 5, using both parallel plate and crimped ribbon arrestors (L = 0.375", D_H = .035"), quenching occurs over a wider range of conditions for downstream ignition. Therefore, the upstream ignition is more severe.

Table 5

Marginal Arrestor Dimensions -- Critical L & D_H

Mixture	Arrestor Type	L (in)	D_H (in)	Approximate threshold mixture velocity (ft/sec): Downstream Ignition	Approximate threshold mixture velocity (ft/sec): Upstream Ignition
Methane/air $\phi = 1.1$	Parallel plate	0.5	.045	Does not quench below 4 ft/sec	Does not reliably quench at any speed
Butane/air $\phi = 1.1$	Parallel plate	0.5	.045	Does not quench below 8 ft/sec	Does not quench at any speed (2-16 ft/sec)
Butane/air $\phi = 1.1$	Crimped Ribbon	0.375	.035	Does not quench below 11 ft/sec	Not reproducible; does not reliably quench at any speed (2-16 ft/sec)

IV. PERFORMANCE OF OFF-THE-SHELF ARRESTORS

A. Purpose of the Tests

The purpose of Task I was to determine the effectiveness of off-the-shelf arrestors in controlling flames for butane/air and gasoline/air mixtures.

B. Approach

The butane/air tests of commercial arrestors were conducted under the most demanding conditions which could be produced using the ADL apparatus (upstream ignition, 5.5 ft run-up distance, constricted pipe exit, and $\phi = 1.1$). This configuration produced flame speeds of 110-125 ft/sec and 150-250 ft/sec for gasoline/air and butane/air, respectively. In addition, single screen and double-screen arrestors were tested under low flame-speed conditions (20-50 ft/sec for butane and 3 ft/sec for gasoline), since the application of these devices is for preventing an exterior flame (presumably traveling at low-speed) from entering the vent system. Their usual location is at the exit end of vent pipes where there is presumably no run-up length sufficient to develop high flame speeds.

The arrestors that were tested are listed in Table 2 (see Chapter II, page 28), and are summarized below in Table 6.

The single layer screen arrestor was prepared for testing by mounting it on the special fixture (see Figure 21) and positioning it in the Varec arrestor housing. The mounting shown in Figure 21 was also used for the Amal and Retimet arrestor elements, and also for the single screen (using a special fixture). An axial housing was fabricated for the Protectoseal arrestor. Standard commercial housings were used for all other arrestors.

Table 6

Off-the-Shelf Arrestors Tested

Type	Source	L (in)	D_H (in)	L/D_H
Single screen	Tyler	-	.022	-
Double screen	Press Vac	-	.040	-
Crimped ribbon	Amal (.024" crimp height)	0.75	.021	35.7
Crimped ribbon	Amal (.045" crimp height)	1.50	.038	39.5
Crimped ribbon	Shand and Jurs	6.00	.045	133.3
Corrugated crimped ribbon	Varec	5.75	.066	87.0
Parallel plate	Protectoseal	1.38	.043	32.0
Metal foam	Retimet No. 30	0.28	.030	9.3

C. Results

Test results are given in Tables 7 and 8 for butane/air and in Tables 9 and 10 for gasoline/air flames, respectively.

Data from the individual tests on off-the-shelf arrestors are listed in Table B-1 of Appendix B.

D. Discussions and Conclusions

1. High-Speed Flames

The Varec Model 50SG, the Shand and Jurs Model 94305-16-11, both the Amal arrestor, and the Retimet foam arrestor successfully controlled high-speed butane/air and gasoline/air flames. The Protectoseal 4956 did not consistently control high-speed butane/air flames, but did control high-speed gasoline/air flames. The marginal performance of the Protectoseal arrestor may be attributed to the .031" gap between plates. Tests reported in Section III.E indicated that above .032" gap, a parallel plate arrestor would allow flame passage.

2. Low-Speed Flames

The results indicate that the single screen of 30 mesh x .011" wire (D_H = .022") can control neither butane/air flames having approach velocities in the 20-50 ft/sec range, nor low speed gasoline/air flames. The Press Vac double screen (20 mesh) arrestor successfully controlled gasoline vapor flames having approach speeds of approximately 3 ft/sec, but exhibited one failure in three runs with the 20-50 ft/sec butane/air flames.

Table 7

Summary of Off-the-Shelf Arrestor Performance
(High speed flames, Butane/air)*

Arrestor Type	Source	Model	Number of Tests	
			Quench	No quench
Crimped ribbon	Amal, Ltd.	188/905/75/24/CN (.024" crimp height)	8	0
Crimped ribbon	Amal, Ltd.	188/905/15/45/CN (.045" crimp height)	5	0
Crimped ribbon	Shand and Jurs	94305-16-11	5	0
Corrugated channel	Varec, Inc.	50SG	5	0
Parallel plate	Protectoseal Co.	4956	7	9
Metal foam	Retimet	No. 30	5	0

*Flame conditions for all tests: $\phi = 1.1$, 16 ft/sec mixture, upstream ignition, 5.5 ft run-up distance, approach speed of flame 150-250 ft/sec.

Table 8

Summary of Off-the-Shelf Arrestor Performance
(Low speed flames, Butane/air)*

Arrestor Type	Source	Model	Number of Tests Quench	No Quench
Single screen	M.S. Tyler	30 mesh x .011" wire	4	6
Double screen	Press-Vac	PL6	2	1
Crimped ribbon	Amal Ltd.	188/905/15/45/Cn (.045" crimp height)	5	0
Parallel plate	Protectoseal	4956	5	0

*Conditions for all tests: $\phi = 1.1$, 4 ft/sec mixture, downstream ignition, 5.5 ft run-up distance, open pipe, approach speed of flame 20-50 ft/sec.

Table 9

Summary of Off-the Shelf Arrestor Performance
(High Speed Flames, Gasoline Vapor/Air)*

Arrestor Type	Source	Model	Number of Tests	
			Quench	No Quench
Double Screen	Press-Vac	PL6	1	2**
Crimped Ribbon	Amal	188/905/75/24/CM	3	0
Crimped Ribbon	Amal	188/905/15/45/CM	4	1†
Crimped Ribbon	Shand and Jurs	94305-6-11	3	0
Corrugated Parallel Plate	Varec	50SG	5	0
Parallel Plate	Protectoseal	4956	3	0
Metal Foam	Retimet	No. 30	3	0

*Flame conditions for all tests: 3 ft/sec mixture speed, upstream ignition, 5.5 ft run-up distance, approach speed of flame approximately 110-125 ft/sec.

**Abnormally low flame speed (50 ft/sec).

†Abnormally high flame speed (≃ 150 ft/sec).

Table 10

Summary of Off-the-Shelf Arrestor Performance
(Low-Speed Flames, Gasoline Vapor/Air)*

			Number of Tests	
Arrestor Type	Source	Model	Quench	No quench
Single Screen	M.S. Tyler	30 mesh x .011"	0	3
Double Screen	Press-Vac	PL6	3	0

*Flame conditions: 3 ft/sec mixture speed, downstream ignition, open pipe, 5.5 ft run-up distance, approach speed of flames 3 ft/sec.

APPENDIX A

TABULATION OF TEST DATA ON THE EFFECT OF MIXTURE SPEED AND IGNITOR LOCATION

Data obtained from individual tests performed during the program are listed in Tables A-1 through 4 according to the following key:

Effect of mixture speed on flame velocity	A-1
Critical mixture velocity for upstream flame propagation	A-2
Effect of upstream ignition	A-3
Critical L & D_H for quenching butane/air and methane/air flames	A-4

Table A-1

Data on Effect of Mixture Speed on Flame Velocity

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
012477-5	Parallel Plate	.022" gap	.031	1.06	34	Butane	1.2	10	68	3	Dn	73	113	✓		
-[illegible]	"	"	"	"	"	"	"	19	"	"	"	56	104	✓		
-[illegible]	"	"	"	"	"	"	"	2	"	"	"	7.5	7.2	✓		Abnormal flame speed
-8	"	"	"	"	"	"	"	10	"	"	"	61	139	✓		
011777-1	"	"	"	"	"	"	1.2	2	"	"	"	67	125	✓		
-2	"	"	"	"	"	"	"	11	"	"	"	111	104	✓		
012177-7	"	"	"	"	"	Methane	"	11	"	"	"	59	139	✓		
-8	"	"	"	"	"	"	"	11	"	"	"	143	78	✓		Abnormal flame signal trace
-9	"	"	"	"	"	"	"	16	"	"	"	61	139	✓		
-11	"	"	"	"	"	"	"	2	"	"	"	2.4	1.2	✓		Abnormal flame speed
012577-1	"	"	"	"	"	"	"	2	"	"	"	42	50	✓		
-2	"	"	"	"	"	"	"	2	"	"	"	44	29	✓		
-3	"	"	"	"	"	"	"	2	"	"	"	27	35	✓		
013177-1	"	"	"	"	"	Butane	"	2	"	"	"	95	74	✓		
-2	"	"	"	"	"	"	"	2	"	"	"	67	97	✓		
-4	"	"	"	"	"	"	"	2	"	"	"	500	420		✓	Abnormal flame speed
-5	"	"	"	"	"	"	"	2	"	"	"	1000	78	✓		
-6	"	"	"	"	"	"	"	2	"	"	"	800	114		✓	
-7	"	"	"	"	"	"	"	2	"	"	"	182	178	✓		
-8	"	"	"	"	"	"	"	2	"	"	"	182	625	✓		

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
020377-13	Parallel Plate	.022" gap	.031	1.06	34	Butane	0.8	18	68	3	Dn	-	-	-	-	No ignition
-14	"	"	"	"	"	"	0.8	18	"	"	"	-	-	-	-	No upstream prop
-15	"	"	"	"	"	"	varied	18	"	"	"	-	-	-	-	Varied ÷ during test
020477-1	"	"	"	"	"	"	1.2	14	"	"	"	57	125	✓		
-2	"	"	"	"	"	"	1.1	5	"	"	"	74	73	✓		
-4	"	"	"	"	"	"	1.1	5	"	"	"	64	98		✓	
-5	"	"	"	"	"	"	"	5	"	"	"	64	170		✓	
-6	"	"	"	"	"	"	"	11	"	"	"	91	62	✓		
-7	"	"	"	"	"	"	"	11	"	"	"	80	54	✓		
-9	"	"	"	"	"	"	"	11	"	"	"	56	192	✓		
020877-1	"	"	"	"	"	"	"	2	"	"	"	67	96	✓		
-2	"	"	"	"	"	"	"	2	"	"	"	125	59		✓	Loud report
020977-1	"	"	"	"	"	"	"	5	"	"	"	-	-	-	-	No ignition
-2	"	"	"	"	"	"	"	5	"	"	"	57	125	✓		
-3	"	"	"	"	"	"	"	5	"	"	"	133	139	✓		
-4	"	"	"	"	"	"	"	5	"	"	"	167	114	✓		
-5	"	"	"	"	"	"	"	5	"	"	"	67	139	✓		

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^{*} ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
013177-9	Parallel Plate	.022" gap	.031	1.06	34	Butane	1.1	2	68	3	Dn	154	179	✓		
020177-1	"	"	"	"	"	"	"	18	"	"	"	80	38		✓	Use of heated Butane hereafter
-2	"	"	"	"	"	"	"	11	"	"	"	43	29		✓	
-3	"	"	"	"	"	"	"	11	"	"	"	56	96	✓		
-4	"	"	"	"	"	"	"	11	"	"	"	71	59	✓		
-5	"	"	"	"	"	"	"	18	"	"	"	0	0	✓		No upstream prop
-6	"	"	"	"	"	"	"	18	"	"	"	0	0	✓		" "
-8	"	"	"	"	"	"	"	2	"	"	"	51	93	✓		
020377-1	"	"	"	"	"	"	"	18	"	"	"	17	16	✓		Delayed propagation
-2	"	"	"	"	"	"	"	18	"	"	"	–	–		✓	
-3	"	"	"	"	"	"	"	18	"	"	"	–	–	✓		
-4	"	"	"	"	"	"	.8	18	"	"	"	–	–	–	–	No ignition
-5	"	"	"	"	"	"	1.3	18	"	"	"	4.6	2.8	✓		
-6	"	"	"	"	"	"	1.1	18	"	"	"	–	–	–	–	No upstream prop.
-7	"	"	"	"	"	"	1.1	18	"	"	"	–	–	–	–	" "
-8	"	"	"	"	"	"	1.1	18	"	"	"	–	–	–	–	" "
-9	"	"	"	"	"	"	1.2	18	"	"	"	–	–	–	–	" "
-10	"	"	"	"	"	"	.8	18	"	"	"	–	–	–	–	No ignition
-11	"	"	"	"	"	"	1.1	18	"	"	"	–	–	–	–	No upstream prop
-12	"	"	"	"	"	"	.9	18	"	"	"	–	–	–	–	" "

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^{*} $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
021177-1	Parallel Plate	.022" gap	.031	1.06	34	Butane	1.10	5	68	3	Dn	133	69	✓		
-2	"	"	"	"	"	"	1.12	11	"	"	"	13.7	10.5		✓	
-3	"	"	"	"	"	"	1.11	18	"	"	"	-	-			No upstream prop
-4	"	"	"	"	"	"	1.10	18	"	"	"	4.1	5.4	✓		Delay in propag.
021777-1	"	"	"	"	"	Methane	1.11	11	"	"	"	56	139			
-2	"	"	"	"	"	"	1.01	2	"	"	"	61	104	✓		
-3	"	"	"	"	"	"	1.11	19	"	"	"	67	125	✓		
-5	"	"	"	"	"	"	1.11	11	"	"	"	61	139	✓		
-6	"	"	"	"	"	"	1.11	19	"	"	"	62	132	✓		
-8	"	"	"	"	"	"	1.11	11	"	"	"	59	156	✓		
-9	"	"	"	"	"	"	1.11	2	"	"	"	54	78	✓		
-10	"	"	"	"	"	"	1.11	18	"	"	"	83	125	✓		
040677-1	Crimped Ribbon	.031 Height	.035	.375	10.7	Butane	1.10	7	68½	"	Up	91	-	✓		
040777-1	"	"	"	"	"	"	1.1	4	"	"	"	143	125	✓		Pres = 21 psi
-2	"	"	"	"	"	"	1.11	7	"	"	"	-	-			No ignition
-3	"	"	"	"	"	"	1.10	10	"	"	"	142	114		✓	Pres = 26 psi
-4	"	"	"	"	"	"	1.07	16	"	"	"	285	208	✓		Pres = 33 psi
-6	"	"	"	"	"	"	1.14	4	"	"	"	167	147		✓	Pres = 10 psi
040877-1	"	"	"	"	"	"	1.2	4	"	"	"	100	100	✓		Pres = 6 psi

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
040877-2	Crimped Ribbon	.031 Height	.035	.375	10.7	Butane	1.08	4	68½	3	Up	153	147	✓		Pres = 28 psi
-3	"	"	"	"	"	"	1.11	4	"	"	"	160	114		✓	Pres = 21 psi
-4	"	"	"	"	"	"	1.11	16	"	"	"	222	156		✓	Pres = 11 psi
-5	"	"	"	"	"	"	-	16	"	"	"	No record		✓		
-6	"	"	"	"	"	"	1.07	16	"	"	"	286	250	✓		Pres = 17 psi
-8	"	"	"	"	"	Methane	1.13	4	"	"	"	69	250	✓		Pres = 7 psi
-9	"	"	"	"	"	"	1.11	14	"	"	"	222	208	✓		Pres = 17 psi
-10	"	"	"	"	"	"	1.14	14	"	"	"	118	250	✓		Pres = 12 psi

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-2

Data on Critical Mixture Velocity for Upstream Flame Propagation

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
021177-5	Parallel Plate	.022" gap	.031	1.06	34	Butane	1.14	4	58	3	Dn	450	380		✓	
-6	"	"	"	"	"	"	1.14	8	"	"	"	91	66	✓		
-7	"	"	"	"	"	"	1.15	6	"	"	"	133	250	✓		Flame-through after 5 sec
-8	"	"	"	"	"	"	1.15	7	"	"	"	105	61		✓	
021477-1	"	"	"	"	"	"	1.14	7	"	None	"	–	–	✓		
-2	"	"	"	"	"	"	1.14	8	"	"	"	–	–		✓	
-3	"	"	"	"	"	"	1.14	10	"	"	"	–	–			No upstream prop
-4	"	"	"	"	"	"	1.12	9	"	"	"	–	–			" "
-5	"	"	"	"	[illegible]	"	1.11	8	"	"	"	–	–			" "
-6	"	"	"	"	"	"	1.11	8	"	"	"	–	–		✓	Flame-through after 5-sec
021577-1	"	"	"	"	"	Methane	1.10	6	"	"	"	6.7	5.4	✓		
-2	"	"	"	"	"	"	1.11	9	"	"	"	–	–			No upstream prop
-3	"	"	"	"	"	"	1.12	8	"	"	"	–	–			" "
-4	"	"	"	"	"	"	1.08	7	"	"	"	6.6	1.7	✓		
-5	"	"	"	"	"	"	1.12	7	"	"	"	–	–			No upstream prop
021677-1	"	"	"	"	"	"	1.11	7	48	"	"	12.3	7.6		✓	
-2	"	"	"	"	"	"	1.11	7	"	"	"	5.4	5.4	✓		
-3	"	"	"	"	"	"	1.11	8	"	"	"	5.5	5.5	✓		
-4	"	"	"	"	"	"	1.11	10	"	"	"	6.1	6.5	✓		Flame through after 5 sec
-5	"	"	"	"	"	"	1.06	12	"	"	"	15.3	6.6	✓		

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-2 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V^*_{23} $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	N	REMARKS
021677-6	Parallel Plate	.022" gap	.031	1.06	34	Methane	1.12	16.9	48	None	Dn	5.9	5.9	✓		
-7	"	"	"	"	"	"	1.12	19	"	"	"	6.1	4.2	✓		
-8	"	"	"	"	"	"	1.11	3.1	"	"	"	-	-	-	-	No ignition
-9	"	"	"	"	"	"	1.11	5	"	"	"	5.9	4.8	✓		Flame-through after 5-sec
-10	"	"	"	"	"	"	1.11	4	"	"	"	23.5	16.7	✓		
-11	"	"	"	"	"	"	1.1	3	"	"	"	3.9	3.9	✓		Flame through after 5-sec
-12	"	"	"	"	"	"	1.10	2.1	"	"	"	-	-	-	-	No ignition

* V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-3

Data on Effect of Upstream Ignition

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V^*_{23} $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
C32177-5	Crimped Ribbon	.031" height	.035	.375	10.7	Butane	1.10	11	68½	3	Dn	64	89	✓		Pres = 12 psi
-6	"	"	"	"	"	"	1.11	10	"	"	"	285	417		✓	Pres = 47 psi
-7	"	"	"	"	"	"	1.11	11	"	"	"	100	61		✓	Pres = 10 psi
032277-1	"	"	"	"	"	"	1.10	11	"	"	"	31	19	✓		Pres = 9 psi
-2	"	"	"	"	"	"	1.10	11	"	"	"	61	96		✓	Pres = 4 psi
-4	"	"	"	"	"	"	1.11	11	"	"	"	36	66		✓	Pres = 10 psi
-5	"	"	"	"	"	"	1.11	11	"	"	"	62	105	✓		Pres = 25 psi
-7	"	"	"	"	"	"	1.15	11	"	"	"	-	-		✓	No Recording
-8	"	"	"	"	"	"	1.15	11	"	"	"	133	83		✓	Pres = 17 psi
-9	"	"	"	"	"	"	1.16	14	"	"	"	65	125		✓	Pres = 47 psi
040677-1	"	"	"	"	"	"	1.10	7	"	"	Up	91	-	✓		
040777-1	"	"	"	"	"	"	1.1	4	"	"	"	143	125	✓		Pres = 21 psi
-2	"	"	"	"	"	"	1.11	7	"	"	"	-	-			No ignition
-3	"	"	"	"	"	"	1.10	10	"	"	"	142	119		✓	Pres = 26 psi
-4	"	"	"	"	"	"	1.07	16	"	"	"	285	208	✓		Pres = 33 psi
-6	"	"	"	"	"	"	1.14	4	"	"	"	167	147		✓	Pres = 10 psi
040877-1	"	"	"	"	"	"	1.2	4	"	"	"	100	100	✓		Pres = 6 psi
-2	"	"	"	"	"	"	1.08	4	"	"	"	153	147	✓		Pres = 28 psi
-3	"	"	"	"	"	"	1.11	4	"	"	"	160	147		✓	Pres = 21 psi
-4	"	"	"	"	"	"	1.11	16	"	"	"	222	156		✓	Pres = 11 psi

* V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-3 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
040877-5	Crimped Ribbon	.031" height	.035	.075	10.7	Butane		16	68½	3	Up	No record		✓		
-6	"	"	"	"	"	"	1.07	16	"	"	"	268	250	✓		Pres = 17 psi
-8	"	"	"	"	"	Methane	1.13	4	"	"	"	69	2ↄ0	✓		Pres = 7 psi
-9	"	"	"	"	"	"	1.11	16	"	"	"	222	208	✓		Pres = 17 psi
-10	"	"	"	"	"	"	1.14	16	"	"	"	118	250	✓		Pres = 12 psi

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-4

Data on Critical L & D_H for Quenching Butane/Air & Methane/Air Flames

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V^*_{23} ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
021777-1	Parallel Plate	.022" gap	.031	1.06	34	Methane	1.11	11.6	68	3	Dn	56	139	✓		
-2	"	"	"	"	"	"	1.01	2	"	"	"	61	104	✓		
-3	"	"	"	"	"	"	1.11	19.2	"	"	"	67	125	✓		
-4	"	"	"	"	"	"	1.10	2	"	"	"	-	-	-	-	No ignition
-5	"	"	"	"	"	"	1.11	11.5	"	"	"	61	139	✓		
-6	"	"	"	"	"	"	1.11	19	"	"	"	62	132	✓		
-7	"	"	"	"	"	"	1.10	2	"	"	"	-	-	-	-	No ignition
-8	"	"	"	"	"	"	1.11	11.5	"	"	"	59	156	✓		Conclude this arrestor is not marginal
-9	"	"	"	"	"	"	1.11	2.0	"	"	"	54	78	✓		
-10	"	"	"	"	"	"	1.11	18	"	"	"	83	125	✓		
0322377-1	Crimped Ribbon	.031" height	.035	0.5	14.3	Methane	1.10	2.1	68½	3	DN	54	114	✓		
-2	"	"	"	"	"	"	1.10	2.1	"	"	"	59	125	✓		
-3	"	"	"	"	"	"	1.05	19.0	"	"	"	56	139	✓		
-4	"	"	"	"	"	"	1.06	19.0	"	"	"	69	125	✓		
022577-1	"	"	"	"	"	"	1.10	18	"	"	"	61	139	✓		
-2	"	"	"	"	"	"	1.10	2	"	"	"	49	42	✓		
-3	"	"	"	"	"	"	1.11	18	"	"	"	62	125	✓		Conclude this arrestor is not marginal
-4	"	"	"	"	"	"	1.10	2	"	"	"	51	50	✓		
-5	"	"	"	"	"	"	1.11	7	"	"	"	167	125	✓		

* V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-4 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
022577-6	Crimped Ribbon	.031" height	.035	.375	10.7	Methane	1.10	2	68½	3	Dn	59	78	✓		
-7	"	"	"	"	"	"	1.11	18	"	"	"	57	178		✓	
-8	"	"	"	"	"	"	1.10	9	"	"	"	56	139	✓		
-9	"	"	"	"	"	"	1.11	13	"	"	"	57	139	✓		
-10	"	"	"	"	"	"	1.11	16	"	"	"	59	156		✓	
-11	"	"	"	"	"	"	1.11	14	"	"	"	57	139	✓		
-12	"	"	"	"	"	"	1.11	15	"	"	"	64	125	✓		
-13	"	"	"	"	"	"	1.11	16	"	"	"	67	125		✓	
-14	"	"	"	"	"	"	1.11	16	"	"	"	61	125		✓	
-15	"	"	"	"	"	"	1.11	16	"	"	"	56	139	✓		
-16	"	"	"	"	"	"	1.11	15	"	"	"	67	139		✓	
-17	"	"	"	"	"	"	1.09	14.5	"	"	"	–	–	✓		
030177-1	"	"	"	"	"	"	1.12	15.8	"	"	"	67	125		✓	Arrestor
-2	"	"	"	"	"	"	1.11	15.8	"	"	"	190	119		✓	may have been
-3	"	"	"	"	"	"	1.12	14.8	"	"	"	59	156		✓	damaged
-4	"	"	"	"	"	"	1.12	14.7	"	"	"	61	125		✓	on these
-5	"	"	"	"	"	"	1.12	12.6	"	"	"	61	139		✓	tests
													Conclude: No speed			critical mix discernable

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-4 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
030177-6	Parallel Plate	.032" gap	.045	.5	11.1	Methane	1.11	7.3	68½	3	Dn	–	–	✓		
-7	"	"	"	"	"	"	1.11	7.3	"	"	"	57	125		✓	
-8	"	"	"	"	"	"	1.11	5.2	"	"	"	61	114		✓	
-9	"	"	"	"	"	"	1.11	2.1	"	"	"	57	66	✓		
-10	"	"	"	"	"	"	1.11	2.1	"	"	"	44	38	✓		
030377-1	"	"	"	"	"	"	1.11	4.1	"	"	"	61	138	✓		
-2	"	"	"	"	"	"	1.11	6.2	"	"	"	64	139		✓	
-3	"	"	"	"	"	"	1.12	5.2	"	"	"	56	132		✓	
-4	"	"	"	"	"	"	1.11	4.2	"	"	"	54	147		✓	
-5	"	"	"	"	"	"	1.11	3.1	"	"	"	51	43	✓		
-6	"	"	"	"	"	"	1.11	4.1	"	"	"	57	96		✓	
-7	"	"	"	"	"	"	1.11	4.1	"	"	"	56	125	✓		
-8	"	"	"	"	"	"	1.1	4.1	"	"	"	54	125	✓		
-9	"	"	"	"	"	"	1.1	4.1	"	"	"	97	86	✓		
-10	"	"	"	"	"	"	1.1	4.1	"	"	"	74	54	✓		
-11	"	"	"	"	"	"	1.1	4.1	"	"	"	133	76		✓	Conclude: Does not quench above 4 ft/sec mix speed
-12	"	"	"	"	"	"	1.1	6.2	"	"	"	64	83	✓		
-13	"	"	"	"	"	Butane	1.1	3.9	"	"	"	65	96		✓	
031077-1	"	"	"	"	"	"	1.1	4.0	"	"	"	250	625		✓	
-2	"	"	"	"	"	"	1.1	10	"	"	"	53	89	✓		

$^*V_{23}$ is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-4 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
031077-3	Parallel Plate	.036" gap	.045	.5	11.1	Butane	1.1	5	68½	3	Dn	250	250		✓	
-4	"	"	"	"	"	"	1.1	8	"	"	"	53	109	✓		
-5	"	"	"	"	"	"	1.1	9	"	"	"	61	100	✓		
-6	"	"	"	"	"	"	1.1	7	"	"	"	67	119	✓		
-7	"	"	"	"	"	"	1.1	6	"	"	"	148	63		✓	
-8	"	"	"	"	"	"	1.1	7.1	"	"	"	111	114		✓	
-9	"	"	"	"	"	"	1.1	6	"	"	"	121	83		✓	
031177-1	"	"	"	"	"	"	1.1	6.1	"	"	"	61	139		✓	
-2	"	"	"	"	"	"	1.1	6.1	"	"	"	105	139		✓	
-3	"	"	"	"	"	"	1.1	6.1	"	"	"	133	104		✓	
-4	"	"	"	"	"	"	1.1	7.2	"	"	"	57	83		✓	
-6	"	"	"	"	"	"	1.1	7.2	"	"	"	56	104		✓	
-7	"	"	"	"	"	"	1.1	8.1	"	"	"	53	63	✓		Conclude: Does not quench below 8 ft/sec mix speed
-8	"	"	"	"	"	"	1.1	8.1	"	"	"	54	96		✓	
-9	"	"	"	"	"	"	1.1	8.1	"	"	"	82	60		✓	
031877-1	Crimped Ribbon	.031" height	.035	.375	10.7	Butane	1.11	4	"	"	"	105	54		✓	
-2	"	"	"	"	"	"	1.10	16	"	"	"	48	40	✓		
-3	"	"	"	"	"	"	1.10	10	"	"	"	43	39	✓		
-4	"	"	"	"	"	"	1.11	7	"	"	"	61	62		✓	

* V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-4 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
031877-5	Crimped Ribbon	.031" height	.035	.375	10.7	Butane	1.11	9	68½	3	Dn	330	250		✓	
-6	"	"	"	"	"	"	1.12	10	"	"	"	64	54		✓	
-7	"	"	"	"	"	"	1.12	10	"	"	"	148	147	✓		
-8	"	"	"	"	"	"	1.12	10	"	"	"	181	83		✓	
032177-1	"	"	"	"	"	"	1.11	10	"	"	"	67	114		✓	
-2	"	"	"	"	"	"	1.11	10	"	"	"	59	125		✓	
-3	"	"	"	"	"	"	1.12	11	"	"	"	57	125	✓		
-4	"	"	"	"	"	"	1.11	11	"	"	"	59	104	✓		
-5	"	"	"	"	"	"	1.10	11	"	"	"	64	89	✓		Pres = 2 psi
-6	"	"	"	"	"	"	1.11	10	"	"	"	285	417		✓	Pres = 47 psi
-7	"	"	"	"	"	"	1.11	11	"	"	"	100	61		✓	Pres = 10 psi
032277-1	"	"	"	"	"	"	1.10	11	"	"	"	31	19	✓		Pres = 9 psi
-2	"	"	"	"	"	"	1.10	11	"	"	"	61	96		✓	Pres = 4 psi
-4	"	"	"	"	"	"	1.11	11	"	"	"	36	66		✓	Pres = 10 psi
-5	"	"	"	"	"	"	1.11	11	"	"	"	32	105	✓		Pres = 25 psi
-7	"	"	"	"	"	"	1.15	11	"	"	"	-	-		✓	No recording
-8	"	"	"	"	"	"	1.15	11	"	"	"	133	83		✓	Pres = 17 psi
-9	"	"	"	"	"	"	1.16	14	"	"	"	65	125		✓	Pres = 47 psi
													Conclude:			Does not quench below 11 ft/sec mix speed

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table A-4(continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
062877-5	Parallel Plate	.036" gap	.045	.5	11.1	Methane	1.1	2	68½	3	Up				✓	
-6	"	"	"	"	"	"	"	"	"	"	"				✓	
-7	"	"	"	"	"	"	"	"	"	"	"				✓	
062777-1	"	"	"	"	"	Butane	"	"	"	"	"				✓	
-2	"	"	"	"	"	"	"	"	"	"	"				✓	
-3	"	"	"	"	"	"	"	"	"	"	"				✓	
-4	"	"	"	"	"	"	"	9	"	"	"				✓	
-5	"	"	"	"	"	"	"	7	"	"	"				✓	
-6	"	"	"	"	"	"	"	5	"	"	"				✓	
-7	"	"	"	"	"	"	"	3	"	"	"				✓	
-8	"	"	"	"	"	"	"	3	"	"	"				✓	
062877-1	"	"	"	"	"	Methane	"	16	"	"	"				✓	
-2	"	"	"	"	"	"	"	4	"	"	"				✓	
-3	"	"	"	"	"	"	"	2	"	"	"				✓	
-4	"	"	"	"	"	"	"	2	"	"	"				✓	

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

APPENDIX B

TABULATION OF TEST DATA ON OFF-THE-SHELF ARRESTORS

Data obtained from individual tests of off-the-shelf arrestors are listed in Table B-1.

Table B-1

Data from Tests on Off-the-Shelf Arrestors

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V^*_{23} $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
051877-6	Single screen	30" mesh x .011" wire	.022	–	–	Butane	1.2	4	69"	None	Dn	12	13	✓		
-7	"	"	"	–	–	"	"	"	"	"	"	26	45	✓		
-8	"	"	"	–	–	"	"	"	"	"	"	20	10	✓		
-9	"	"	"	–	–	"	"	"	"	"	"	22	11		✓	
-10	"	"	"	–	–	"	"	"	"	"	"	25	66		✓	
051977-1	"	"	"	–	–	"	"	"	"	"	"	22	17		✓	New screen used
-2	"	"	"	–	–	"	"	"	"	"	"	26	31		✓	
-3	"	"	"	–	–	"	"	"	"	"	"	15	15		✓	
-4	"	"	"	–	–	"	"	"	"	"	"	22	11	✓		
-5	"	"	"	–	–	"	"	"	"	"	"	13	17		✓	
041977-1	Varec	.047" gap	.066	5.75	87	"	1.14	16	64	3	Up	250	–	✓		Pres. = 6 psi
-2	"	"	"	"	"	"	1.15	"	"	"	"	250	–	✓		Pres = 4 psi
-3	"	"	"	"	"	"	1.14	"	"	"	"	250	–	✓		Pres = 4 psi
-4	"	"	"	"	"	"	1.14	"	"	"	"	143	–	✓		Pres = 4 psi
-5	"	"	"	"	"	"	1.14	"	"	"	"	268	–	✓		Pres = 4 psi
042277-1	Amal	.024" height	.021	.75	35.7	"	1.08	"	68	"	"	–	–	✓		No record taken
-2	"	"	"	"	"	"	1.13	"	"	"	"	200	250	✓		Pres = 7 psi
-3	"	"	"	"	"	"	1.09	"	"	"	"	200	179	✓		Pres = 13 psi
G42577-1	"	"	"	"	"	"	1.12	"	"	"	"	250	156	✓		Pres = 7 psi
-2	"	"	"	"	"	"	1.11	"	"	"	"	182	208	✓		Pres = 7 psi

* V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor. respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table B-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
042577-3	Amal	.024" height	.021	.75	35.7	Butane	1.12	16	68	3	Up	400	125	✓		Pres = 12 psi
-4	"	"	"	"	"	"	1.07	"	"	"	"	143	125	✓		Pres = 7 psi
-5	"	"	"	"	"	"	1.07	"	"	"	"	167	139	✓		Pres = 7 psi
-6	"	"	"	"	"	"	1.09	"	"	"	"	118	139	✓		Pres = 15 psi
050277-1	"	"	"	"	"	"	1.21	4	"	None	Dn	4.8	-	✓		
-2	"	"	"	"	"	"	1.11	"	"	"	"	2.8	-	✓		
-3	"	"	"	"	"	"	1.25	"	"	"	"	3.6	-	✓		
-4	"	"	"	"	"	"	1.22	"	"	"	"	3.2	-	✓		
-5	"	"	"	"	"	"	1.11	"	"	"	"	2.9	-	✓		
-6	"	"	"	"	"	"	1.10	"	"	"	"	3.6	-	✓		
-7	"	"	"	"	"	"	1.11	"	"	"	"	2.2	-	✓		
-8	"	"	"	"	"	"	1.23	"	"	"	"	4.6	-	✓		
050477-1	"	"	"	"	"	"	1.26	"	"	"	"	3.2	3.2	✓		
-2	"	"	"	"	"	"	1.22	"	"	"	"	4.9	3.5	✓		
-3	"	"	"	"	"	"	1.21	"	"	"	"	4.3	5.2	✓		
-4	"	"	"	"	"	"	1.22	"	"	"	"	4.3	2.9	✓		
-5	"	"	"	"	"	"	1.21	"	"	"	"	3.2	2.3	✓		
051077-1	Amal	.045" height	.038	1.5	39	"	1.1	16	67½	"	Up	-	89		✓	Faulty data**
-2	"	"	"	"	"	"	1.1	"	"	"	"	125	139	✓		" "
-3	"	"	"	"	"	"	1.1	"	"	"	"	167	139	✓		" "

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

**These runs with the Amal .045" crimp arrestor were faulty because a gap was noticed in the mounting assembly. Repeat tests conducted after repairing the gap showed no failure.

Table B-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
051177-1	Amal	.045" height	.038	1.5	39	Butane	1.1	16	c.½"	None	Up	182	214		✓	Faulty data**
-2	"	"	"	"	"	"	"	"	"	"	"	222	188		✓	" "
051377-1	"	"	"	"	"	"	"	"	"	"	"	200	139	✓		" "
051677-1	"	"	"	"	"	"	"	"	"	3	"	167	139	✓		" "
-2	"	"	"	"	"	"	"	"	"	"	"	200	156		✓	" "
-3	"	"	"	"	"	"	"	"	"	"	"	222	179		✓	" "
-4	"	"	"	"	"	"	"	"	"	"	"	200	139		✓	" "
-5	"	"	"	"	"	"	"	"	"	"	"	167	139		✓	" "
051777-3	"	"	"	"	"	"	"	"	"	"	"	154	125		✓	" "
-4	"	"	"	"	"	"	"	"	"	"	"	111	114		✓	" "
-5	"	"	"	"	"	"	"	"	"	"	"	143	156		✓	" "
-6	"	"	"	"	"	"	"	"	"	"	"	135	125		✓	" "
-7	"	"	"	"	"	"	"	"	"	"	"	154	139		✓	" "
-8	"	"	"	"	"	"	"	"	"	"	"	235	208		✓	" "
051877-1	"	"	"	"	"	"	1.2	4	"	None	Dn	26	34	✓		" "
-2	"	"	"	"	"	"	"	"	"	"	"	14	26	✓		
-3	"	"	"	"	"	"	"	"	"	"	"	25	33	✓		
-4	"	"	"	"	"	"	"	"	"	"	"	14	25	✓		
-5	"	"	"	"	"	"	"	"	"	"	"	15	24	✓		Arrestor O.K.

* V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

** These runs with the Amal .045" crimp arrestor were faulty because a gap was noticed in the mounting assembly. Repeat tests conducted after repairing the gap showed no failure.

Table B-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS: Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS: Fuel	ϕ	Mix speed (ft/sec)	IGNITION: Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS: V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
052677-1	Shand & Jurs	.05 height x .14 width	.045	6	133	Butane	1.1	16	62	3	Up	97	167	✓		Velocities to be determined
-2	"	"	"	"	"	"	"	"	"	"	"	121	80	✓		" "
-3	"	"	"	"	"	"	"	"	"	"	"	88	143	✓		" "
-4	"	"	"	"	"	"	"	"	"	"	"	117	222	✓		" "
-5	"	"	"	"	"	"	"	"	"	"	"	80	167	✓		" "
052777-1	Protecto-seal	.0[illegible]1" gap	.043	1.38	32	"	"	"	"	"	"	103	222	✓		" "
-2	"	"	"	"	"	"	"	"	"	"	"	109	286	✓		" "
-3	"	"	"	"	"	"	"	"	"	"	"	117	250	✓		" "
-4	"	"	"	"	"	"	"	"	"	"	"	95	200	✓		" "
-5	"	"	"	"	"	"	"	"	"	"	"	92	167		✓	" "
-6	"	"	"	"	"	"	"	"	"	"	"	90	167		✓	" "
053177-1	"	"	"	"	"	"	"	"	"	"	"	109	200		✓	" "
-2	"	"	"	"	"	"	"	"	"	"	"	73	182	✓		" "
-3	"	"	"	"	"	"	"	"	"	"	"	88	167		✓	" "
-4	"	"	"	"	"	"	"	"	"	"	"	73	143		✓	" "
-5	"	"	"	"	"	"	"	"	"	"	"	83	200		✓	" "

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table B-1 (Continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	ϕ	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^{*} ($\frac{ft}{sec}$)	V_{34} ($\frac{ft}{sec}$)	Quench Y	Quench N	REMARKS
061077-1	Protectoseal	.031" gap	.043	1.38	32	Butane	1.1	4	62	3	Up	167	–	✓		
-2	"	"	"	"	"	"	"	"	"	"	"	154	–	✓		
-3	"	"	"	"	"	"	"	"	"	"	"	154	–		✓	
-4	"	"	"	"	"	"	"	"	"	"	"	143	–		✓	
-5	"	"	"	"	"	"	"	"	"	"	"	200	–		✓	
060277-1	"	"	"	"	"	"	"	"	"	None	Dn	8	–	✓		Purpose: To determine low flame speed quench properties.
-2	"	"	"	"	"	"	"	"	"	"	"	8	–	✓		
-3	"	"	"	"	"	"	"	"	"	"	"	8	–	✓		
-4	"	"	"	"	"	"	"	"	"	"	"	8	–	✓		
-5	"	"	"	"	"	"	"	"	"	"	"	8	–	✓		
062477-4	Amal	.045" height	.035	1.5	39.5	Butane	1.1	16	67	3	Up	–	100	✓		
-5	"	"	"	"	"	"	"	"	"	"	"	–	125	✓		
-6	"	"	"	"	"	"	"	"	"	"	"	–	73	✓		
-7	"	"	"	"	"	"	"	"	"	"	"	105	96	✓		
-8	"	"	"	"	"	"	"	"	"	"	"	133	114	✓		
076177-4	Press-Vac	Dbl Screen 30 mesh	.035	–	–	Butane	1.1	4	68	None	Dn	4	5	✓		
-5	"	"	"	"	"	"	"	"	"	"	"	5	5		✓	
-6	"	"	"	"	"	"	"	"	"	"	"	5	6	✓		

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Table B-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	Fuel fraction (%)	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^{*} $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
062077-6	Amal	.045" Hgt	.038	1.5	39.5	Gasoline	4.0	3	67	6	Up	154	42		✓	
-7	"	"	"	"	"	"	3.9	"	"	"	"	111	103	✓		
-8	"	"	"	"	"	"	3.2	"	"	"	"	125	114	✓		
-9	"	"	"	"	"	"	3.0	"	"	"	"	118	114	✓		
062177-1	Verec	.047" Gap	.066	5.75	87	"	3.0	"	64	"	"	-	-	✓		
-2	"	"	"	"	"	"	1.7	"	"	"	"	125	-	✓		
062277-1	"	"	"	"	"	"	2.1	"	"	"	"	74	-	✓		
-2	"	"	"	"	"	"	2.3	"	"	"	"	111	-	✓		
-3	"	"	"	"	"	"	2.7	"	"	"	"	111	-	✓		
-4	Amal	.024" Hgt	.021	.75	35.7	"	2.7	"	68	"	"	100	69	✓		
-5	"	"	"	"	"	"	2.9	"	"	"	"	111	83	✓		
-6	"	"	"	"	"	"	3.0	"	"	"	"	111	89	✓		
-7	Retimet	Grade 30	.030	.28	9.3	"	2.5	"	68½	"	"	91	69	✓		
-8	"	"	"	"	"	"	2.3	"	"	"	"	100	89	✓		
-9	"	"	"	"	"	"	2.5	"	"	"	"	95	83	✓		
062477-1	Screen	30 mesh x .11 dia wire	.044	-	-	Gasoline	2.5	3	69	2	Dn	3	4		✓	
-2	"	"	"	-	-	"	4.1	"	"	"	"	18	25		✓	
-3	"	"	"	-	-	"	3.4	"	"	"	"	4	4		✓	

*V_{23} is the average flame speed between points 2 and 3 located 41" and 17" from the base-plate of the arrestor, respectively. Similarly V_{34} is the flame speed based on point 3 (17") and point 4 (2") from the opposite site of the arrestor.

Table B-1 (continued)

Test Number	ARRESTOR CHARACTERISTICS Type	Opening	D_H (in)	L (in)	L/D_H	MIXTURE CHARACTERISTICS Fuel	Fuel Fraction (%)	Mix speed (ft/sec)	IGNITION Run-up (in)	Orifice dia. (in)	Up or down-stream	RESULTS V_{23}^* $(\frac{ft}{sec})$	V_{34} $(\frac{ft}{sec})$	Quench Y	Quench N	REMARKS
062977-1	Protectoseal	.031" gap	.043	1.38	32.1	Gasoline	2.6	3	62	1	Up	62	–	√		
-2	"	"	"	"	"	"	2.5	"	"	"	"	50	–	√		
-3	"	"	"	"	"	"	2.8	"	"	"	"	24	–	√		
-4	Shand & Jurs	.05" Hgt x .14 wide	.045	6	133	"	3.3	"	"	"	"	29	–	√		
-5	"	"	"	"	"	"	3.5	"	"	"	"	71	–	√		
-6	"	"	"	"	"	"	3.3	"	"	"	"	28	–	√		
063077-1	"	"	"	"	"	"	2.9	"	"	"	"	87	–	√		
-2	"	"	"	"	"	"	3.5	"	"	"	"	49	–	√		
-3	"	"	"	"	"	"	3.9	"	"	"	"	65	–	√		
-4	"	"	"	"	"	"	2.9	"	"	"	"	83	–	√		
-5	Press Vac	Dbl 20 mesh screen	.038	–	–	"	3.0	2	68	2	Dn	3	–	√		
-6	"	"	"	–	–	"	3.7	"	"	"	"	3	–	√		
-7	"	"	"	–	–	"	3.5	"	"	"	"	3	–	√		
070177-1	"	"	"	–	–	"	3.5	"	"	1	"	34	–	√		
-2	"	"	"	–	–	"	4.5	"	"	"	"	44	–		√	
-3	"	"	"	–	–	"	2.2	"	"	"	"	51	–		√	

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